PRE-STRESSED MODULAR RETAINING WALL SYSTEM AND METHOD

Inventor: Cyrrus Gregory Lewis

Background of the Invention

Field of the Invention

The present invention relates to a system and method for fabricating a pre-stressed modular construction for supporting or retaining an applied load. More particularly, the present invention relates to a system and method for pre-stressed modular retaining walls.

Related Art

A retaining wall is an engineered structure that has the particular task of ensuring that a given unstable, or potentially unstable, soil mass is prevented from moving under the influence of gravity. Frequently, the retaining wall is also called upon to withstand a superimposed load, a surcharge load, on and/or within the soil mass, such as a highway, together with its traffic loading, or the loading induced by the foundations of a building located in close proximity to the retaining structure. Further, the retaining wall may be required to support some other non-retaining load that is resisted by structural elements directly attached to, and/or incorporated within, the wall structure itself.

Since the early 1970's, numerous alternative wall systems have been introduced. Examples of these systems include mechanically stabilized earth (MSE) walls and reinforced soil slopes (RSS) employing metallic or polymeric internal reinforcement; anchored walls, such as the soldier pile and lagging walls, diaphragm walls, and soil mixed walls; prefabricated modular gravity wall systems including cribs, bins, and gabions; and in-situ reinforced wall systems such as soil-nailed walls and micropile walls. However, because of the ever increasing demands that

are being placed on our city and urban environments and, most noticeably, on the country's transportation infrastructure, together with the need to preserve our natural environment while providing for the associated societal expectations, there is an increasing number of problematic sites where the currently available retaining wall options cannot provide an optimal solution. In particular, for those sites that require "foundation-up" construction, there is a dearth of rapid construct, high capacity retaining wall systems possessing significant functional flexibility and which demand only a small construction footprint. Retaining structures constructed to resist soil pressures are often categorized according to their basic mechanisms of retention. The retention mechanisms include internally stabilized, externally stabilized, and hybrid systems. Alternatively, retaining walls may be categorized according to their source of support, that is, their source of equilibrating reaction forces. The sources of support for these retaining walls may be bracketed into gravity, semigravity, and nongravity.

An internally stabilized system involves reinforced soils to retain a soil mass and any surcharge loads. This reinforcing may be provided by adding reinforcement directly to the soil mass, where this augmented soil mass is providing the retaining/self-retaining structure, as the system is being constructed from the "ground" up. Various types of reinforcement are available, and the soils between the layers of reinforcement are placed in a carefully controlled manner meeting design specifications - that is, the placed soil is "engineered fill." Frequently, pre-cast concrete elements are tied directly to these soil reinforcing components. This system forms the basic approach of Mechanically Stabilized Earth, MSE, retaining wall systems.

Alternatively, this internal stabilization via the reinforcing of the soil mass in question may proceed from the top down. In this (directionally) opposite approach, reinforcing elements are added to the existing soil mass in order to provide the existing materials with a greater degree of

internal stability. As an example of this approach, the face, that is exposed as the excavation proceeds from the top down, has soil nails installed through it into the ground mass, which nails extend beyond any potential failure plane. Often, a shotcrete cover over the exposed face is placed and subsequently connected to these nails, thereby providing a protection against erosion of the soil face.

Further to the above methods of reinforcing a soil mass, driven piles or cast-in-drilled-hole piles may be used to stabilize the mass of concern. However, this approach is generally considered when the stability issue is more global in nature. By "global" is meant the situation where a body of soil is experiencing a deep-seated instability, which instability ideally needs to be eliminated.

With externally stabilized systems, a physical structure is employed to confine the body of soil. The equilibrating reaction forces, required by an externally stabilized system, are provided either through the weight of a morpho-stable structure, or by the reactions mobilized via the inclusion and/or extension of various system elements into "reaction zones". The latter reactions may be generated by driving the piles of a sheet-pile wall system, for example, to sufficient depths into competent soil. Or, reactions may be generated via the use of ground anchors providing point-reactions on the externally stabilizing structure. Frequently, combinations of reaction-force-providing structural elements are employed, in a given situation, to deliver the total force equilibration required for an externally stabilized retaining wall.

With regard to sources of support, that is, with regard to the sources of the equilibrating reaction forces, retaining wall systems may be categorized into three groups. These are the groupings of (1) gravity walls, (2) semigravity walls, and (3) nongravity walls.

Gravity walls derive their capacity to resist imposed soil loads through the dead weight of the wall itself (that is the physical wall that is constructed) or through an integrated mass that can be either internally or externally stabilized. Gravity walls may be further classified into four types as follows. The first type is an internally stabilized soil mass system. Some of the examples given above are typical. The stability of a cut slope may be maintained in a top-to-bottom installation of soil nails, installed as the excavation of materials proceeds. Or, a retaining soil mass may be constructed of engineered fill, in a bottom-to-top sequence, thereby creating a soil mass possessing the required internal stability via the inclusion of reinforcing elements at regular vertical spacing. Where the soil mass is constructed from engineered fill, the face of such soil mass may be protected by using pre-cast concrete facings as with many MSE systems. Where soil nails are used, the front face is preferably protected using shotcrete or cast-in-place concrete. The second type of gravity wall is an externally stabilized soil mass system. Included in this category are simple modular pre-cast concrete walls. Such simple pre-cast concrete walls are stacked, but include no internal mechanism for enhancing structural capacity. Another example is prefabricated metal bin walls. The third type is also an externally stabilizing system. In this category are the generic walls including the masonry walls, the stone walls, "dumped" (usually shaped) rock walls, and the contained rock walls, often using uniform crushed rock and known as gabion walls. The fourth system is also an externally stabilizing system. Examples are the use of cast-in-place mass concrete wall, or the cement-treated soil wall. Where the face of the treated soil wall requires protection, a pre-cast concrete panel may be used, which panel would be anchored to the treated-soil wall.

Semigravity walls derive their restraining capability through the combination of dead weight and structural resistance. Generally, these semigravity walls are externally stabilizing

structures. They may be constructed on spread footings or on deep foundations. Historically, the dominant type of semigravity retaining wall is the conventional cast-in-place concrete cantilever structure. Alternatively, various kinds of pre-cast concrete walls are available in the market, which walls are constructed on cast-in-place footings. Cantilever semi-gravity retaining walls may be very reliant on the dead weight of the soil mass that rests on the section of the foundation footing that extends back beyond the wall's stem, while also developing the necessary structural resistance. An example of the necessary structural resistance would be the wall's moment and shear capacity at the base of the stem.

Nongravity walls derive their restraining capability through lateral resistance. This lateral resistance may be mobilized in a number of ways. For example, the continuation of vertical structural elements down to competent soils, or the use of ground anchor retainers directly delivering point resistance to the retaining structure. Examples of externally stabilizing nongravity systems are embedded cantilevering wall elements, sheet piles, drilled shafts, or slurry walls. A second group of nongravity walls includes the first listing of embedded walls but have additional restraint via utilizing multiple ground anchor retainers.

Where, for example, there is a need to arrest the creep movement of a slope, nongravity systems may be employed in the form of dowel piles or caissons, to internally stabilize the soil mass. It should be noted that required equilibrating forces may be developed via the use of reaction members which develop point-reaction-forces. (Consider the reactions to a truss, which truss transfers moment to its support). That is, the structural elements delivering resistance to the retaining wall structure overall may have so little moment (and shear) resisting capacity, if any, that the equilibrating set of forces are established via point-acting reaction forces. For example, an arrangement of elements for such a system, may consist of a set of vertical (or near vertical)

piles, a set of (near) vertical ground anchors and, finally, a set of (near) horizontal ground anchors. In this case, the piles would take up compression loads, the (near) vertical ground anchors would provide a (predominantly) downward reaction, which would act in concert with the piles' upward reaction to provide moment resistance to the base foundation. The (near) horizontal ground anchors, placed appropriately at the foundation beam/pile cap level, would resist the net "shear" forces from the retaining wall structure that would cause the foundation element to translate.

An example of a retaining wall is shown, for example, in U.S. Patent No. 2,149,957 ("the Dawson patent"). The wall of the Dawson patent utilizes stretchers and headers to construct a retaining wall. Dawson further discloses "positive tensile anchorage." Such "positive tensile anchorage" refers to the construction of the individual elements and has no impact on the primary behavior of the system disclosed in the Dawson patent. Moreover, the wall of the Dawson patent does not pre-stress header assemblies through post-tensioning. Further, the Dawson patent does not disclose vertically disposed passive reinforcement through the header assemblies.

Retaining wall systems, such as those shown in the Dawson patent, often do not provide an optimal solution for retaining or supporting an applied load. The design of conventional retaining wall systems may result in constructibility problems, resulting in longer construction periods, higher cost, and more extensive use of the surrounding land. Thus there is a need in the art for a retaining wall system that provides an improved solution for retaining or supporting an applied load and overcomes the limitations of constructibility problems with existing systems. There is a further need in the art for a retaining wall system that is modular and adaptable to a wide variety of construction needs.

Summary of the Invention

The present invention solves the problems with, and overcomes the disadvantages of conventional retaining wall systems. Accordingly, the present invention provides a system and method for constructing a pre-stressed modular construction for supporting or retaining an applied load. The retaining wall systems of the present invention are specifically designed to provide the owner, architect, engineer, and constructor with retaining wall solutions that most adequately provide for more difficult sites and/or increased performance expectations.

The present invention relates to a system and method for constructing a pre-stressed modular construction for supporting or retaining an applied load. In particular, the present invention relates to a system and method for constructing pre-stressed modular retaining walls. In one aspect of the present invention, a system for constructing a pre-stressed modular construction for retaining or supporting an applied load is provided. The system comprises a header stack, wherein the header stack is comprised of a plurality of header units; and an active reinforcement element configured to cooperate with the header stack so that post-tensioning the active reinforcement element imparts a corresponding pre-stressing force into the header stack. In one embodiment of the invention, the header units that make up the header stack comprise a center element having a top face, and a bottom face; a first end element disposed at one end of said center element; and a second end element disposed at another end of said center element.

The system may comprise active reinforcement elements disposed external to the header stack. In such a configuration, there may be passive reinforcement elements disposed internal to the header stack. Additionally, active reinforcement elements may be disposed internal to the header stack.

In another aspect of the system, the header units that make up the header stack comprise a top face and a bottom face; a base element having a first end and a second end; a head element having a first end and a second end; and a pair of side elements extending between each of the first end and the second end of the base element and the head element. The system further comprises a structural member for coupling two or more header stacks and a complementary structural element disposed between two header units and extending between two or more header stacks.

In another aspect of the invention, a pre-stressed modular construction for retaining or supporting an applied load is provided. The construction comprises a plurality of header stacks, wherein each of the header stacks comprises a plurality of header units; and a plurality of active reinforcement elements configured to cooperate with at least one of the header stacks so that post-tensioning the active reinforcement element imparts a corresponding pre-stressing force into the header stack. There are a plurality of structural members, wherein each of the structural members is coupled to at least one of the header stacks. In an exemplary embodiment of the construction, the header units that make up the header stack comprise a center element having a top face, and a bottom face; a first end element disposed at one end of the center element; and a second end element disposed at another end of the center element.

In another aspect of the pre-stressed modular construction, the header units that make up the header stack comprise a top face and a bottom face; a base element having a first end and a second end; a head element having a first end and a second end; and a pair of side elements extending between each of the first end and the second end of the base element and the head element. The construction further comprises a structural member for coupling two or more

header stacks and a complementary structural element disposed between two header units and extending between two or more header stacks.

In a further aspect of the invention, a pre-stressed modular construction for retaining or supporting an applied load is provided. The pre-stressed modular construction preferably comprises at least two header stacks, each of the header stacks being comprised of a plurality of stacked header units. There is also preferably at least one pre-stressing tendon for each of the header stacks, with each pre-stressing tendon being configured to cooperate with its header stack so that post-tensioning the pre-stressing tendon prior to application of the applied load imparts a corresponding pre-stressing force into its header stack at at least one lock-off point. There is also a structural member coupled to the at least two header stacks. The pre-stressed modular construction further preferably comprises a tieback transfer beam disposed between two of the header units and extends between the at least two header stacks. There is also a ground anchor coupled to the tieback transfer beam. The structural member can be a concrete stretcher, a pre-cast concrete panel, a cast-in-place concrete panel, a cast-in-place concrete arch, or shotcrete.

In another aspect of the invention, a method of fabricating a pre-stressed modular construction for retaining or supporting an applied load is provided. The method comprises providing a foundation for the construction; constructing a plurality of header stacks on the foundation, with each header stack being comprised of a plurality of header units; coupling an active reinforcement element to each header stack; and post-tensioning the active reinforcement element such that it imparts a corresponding pre-stressing force into the header stack. The constructing step comprises stacking a plurality of header units. The coupling step comprises pre-positioning the active reinforcement element in the foundation; feeding the header units over the active reinforcement element, the active reinforcement element passing through passthrough

ducts in the header units; and securing the active reinforcement element to the header stack. In a configuration where external active reinforcement elements are used, the active reinforcement elements may be locked off in a variety of ways. The active reinforcement elements may be locked off at external coupling devices coupled to the header stack, or locked off at a complementary structural element.

In a further aspect of the invention, a method of fabricating a pre-stressed modular construction for retaining or supporting an applied load is provided comprising the steps of suspending a plurality of header units; casting a foundation beneath the header units; constructing a plurality of header stacks on the cast foundation, wherein each header stack is adjacent one of the plurality of suspended header units; coupling an active reinforcement element to the header stack; and post-tensioning the active reinforcement element such that it imparts a corresponding pre-stressing force into the header stack.

In a further aspect of the present invention, a method of fabricating a pre-stressed modular construction for retaining or supporting an applied load is provided. The method comprises the steps of providing a foundation for the construction; constructing a plurality of header stacks on the foundation, wherein each header stack comprises a plurality of header units; coupling an active reinforcement element to each header stack; post-tensioning the active reinforcement element such that it imparts a corresponding pre-stressing force into at least one of the header stacks; providing additional header units to at least one of the header stacks; and repeating the step of post-tensioning after application of another portion of the applied load. In a still further aspect of the present invention, a method of fabricating a pre-stressed modular construction for retaining or supporting an applied load is provided. The method comprises the steps of providing a foundation for the construction; constructing a plurality of header stacks on the foundation, wherein each header stack

comprises a plurality of header units; coupling an active reinforcement element to each header stack; imparting a portion of the applied load to the modular construction; post-tensioning the active reinforcement element such that it imparts a corresponding pre-stressing force into at least one of the header stacks; providing additional header units to at least one of the header stacks; and repeating the step of post-tensioning after application of another portion of the applied load.

Features and Advantages

An advantage of the present system is that structural pre-stressing may be sequentially modified, most typically increased, as the soil loading on the retaining wall changes.

Another advantage of the present system is that retaining wall (vertical) sections may be given sufficient and/or final pre-stress so as to allow for the construction of other structural members. If necessary, this could all take place before the soil loads are placed on the wall.

A further advantage of the present system is that the retaining wall structure may be stressed so as to always possess "residual", or "net", compressive stress on the "tension" side of any given header stack cross-section. This latter characteristic would be called on in environmentally hostile situations. For example, environmentally hostile situations may exist where naturally aggressive minerals are present in the ground water in contact with, or in close proximity to, the retaining wall, or where the retaining wall is a sea wall.

An advantage of the system of the present invention is ready availability. Short period cyclic casting of standardized structural modules assures that structural components are produced in sufficient quantities to satisfy fast track construction schedules.

A further advantage of the system of the present invention is superior quality control. Plant-cast pre-cast concrete components are manufactured under optimum conditions of forming,

fabrication and placement of the reinforcement, inclusion of pre-stressing passthrough ducts and other embedded items and features. The optimally controlled placement and compaction of low slump concrete having optimized mix design and control, along with favorable curing conditions, typically not achievable on site, further significantly increase the in-service performance of these elements.

Yet another advantage of the system of the present invention, for retaining wall construction possessing a given structural capacity, is reduced construction depth. High performance concrete is easily achievable. For any given loading conditions, via the correct selection of (sub)group of components, the retaining structure depth may be minimized, a significant advantage where space is at a premium.

Another advantage of the system of the present invention is its high load-resisting capacity. For a given set of spatial restrictions and/or for a given volume of materials used, pre-cast pre-stressed concrete offers greater structural strength and rigidity. These attributes become very significant in many applications.

A further advantage of the system of the present invention is its durability. Pre-cast concrete, in particular high-performance pre-cast concrete, is exceptionally resistant to weathering, abrasion, impact and corrosion. The resulting structures have great resistance to the deleterious effects found in hostile environments.

Yet another advantage of the system of the present invention is its long economic life. The reliability of currently available pre-stressing systems and the durability characteristics of the pre-cast elements allow for the economic construction of very-long-life retaining and/or support structures. Pre-stressing reduces or, if required, completely eliminates tension cracks, and

thereby guarantees the integrity of the concrete and the protection of the embedded steel elements.

Another advantage of the system of the present invention is derived from the use of architectural concrete. The process of pre-casting concrete components, for example, the pre-cast panels that may be used with certain embodiments of the present invention, lends itself to the sculpturing of these exposed elements, and the consequent enhanced appearance of the final structure.

Still another advantage of the system of the present invention is the flexibility of construction sequence. The application of pre-stress, in particular the staged and/or sequenced application of pre-stress, to the assemblies of pre-cast concrete modules in these systems allows for sequenced construction without re-setup penalties.

Another advantage of the system of the present invention is the control of shrinkage and creep, and the consequent effects of same, which control can essentially be "dialed up." In this regard, the ready quality control of concrete products, that are manufactured via plant-cast pre-casting, affords greater accuracy in the determination of anticipated shrinkage and creep. With knowledge of the characteristics of pre-stressing components and the concrete characteristics of the various modules, along with the control of the pre-stressing stress magnitudes and distributions, the shrinkage and creep may be accurately predetermined.

Another advantage of the system of the present invention is the reduction or complete elimination of site formwork. Certain embodiments of the invention, as built above foundation level, are constructed entirely independent of cast-in-place concrete.

A further advantage of the present invention is its speed of construction. The fact that all embodiments can employ pre-cast header modules, used to form the header stacks, and some can

be completely comprised of pre-cast elements, contributes significantly to the guaranteed speed of erection. One of the principal aims of these systems is to provide retaining wall and/or support structural systems that, not only provide high capacity, but may be erected with great rapidity.

Additional features and advantages of the invention will be set forth in the description that follows, and in part will be apparent from the description, or may be learned in practice of the invention.

Brief Description of the Drawings

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the features, advantages, and principles of the invention.

Fig. 1 is a perspective view of an exemplary system according to the present invention.

Fig. 2 is a perspective view of an alternative exemplary embodiment of the system according to the present invention.

Fig. 3 is an exploded perspective view of an alternative embodiment of the system according to the present invention.

Fig. 4 is an exploded perspective view of an alternative embodiment of the system according to the present invention.

Fig. 5 is a perspective view of an alternative exemplary embodiment of the system according to the present invention.

Fig. 6a is a plan view of an exemplary embodiment of a header according to the present invention.

Fig. 6b is a plan view of an alternative exemplary embodiment of a header according to the present invention.

Fig. 6c is a plan view of an alternative exemplary embodiment of a header according to the present invention.

Fig. 6d is a plan view of an alternative exemplary embodiment of a header according to the present invention.

Fig. 6e is a side view of an exemplary embodiment of a header according to the present invention.

Fig. 7a is a perspective view of an alternative exemplary embodiment of a header according to the present invention.

Fig. 7b is a top plan view of the exemplary header in Fig. 7a.

Fig. 7c is a side elevation of the exemplary header in Figs. 7a and 7b.

Fig. 8 is a perspective view of one embodiment of a modular construction according to the present invention.

Fig. 9 is a perspective view of an alternative embodiment of a modular construction according to the present invention.

Fig. 10 is a perspective view of an alternative embodiment of a modular construction according to the present invention.

Fig. 11 is a perspective view of an alternative embodiment of a modular construction according to the present invention including a complementary structural element.

Fig. 12 is a perspective view of an alternative embodiment of a modular construction according to the present invention including cast-in-place concrete panels.

Fig. 13 is a perspective view of an alternative embodiment of a modular construction according to the present invention.

Fig. 14a is a perspective view of a partial modular construction according to the present invention.

Fig. 14b is a perspective view of an exemplary header in a partial modular construction according to the present invention.

Fig. 15a is a perspective view of an exemplary header in a partial modular construction according to the present invention.

Fig. 15b is a perspective view of an exemplary header in a partial modular construction according to the present invention.

Fig. 16 is a perspective view of an alternative exemplary embodiment of the system according to the present invention including exemplary active and passive reinforcement elements.

Fig. 17 is a detailed perspective view of a lock-off element according to the present invention.

Fig. 18 is a perspective view of an alternative exemplary embodiment of the system according to the present invention including exemplary active and passive reinforcement elements.

Fig. 19 is a perspective view of an alternative exemplary embodiment of the system according to the present invention including exemplary active and passive reinforcement elements and harping elements.

Fig. 20 is a detailed view of an exemplary harping element of Fig. 19.

Fig. 21a is a side elevation of an exemplary embodiment of a header according to the present invention.

Fig. 21b is a perspective view of the header in Fig. 21a.

Fig. 21c is a side elevation of an alternative exemplary embodiment of a header according to the present invention.

Fig. 21d is a perspective view of the header in Fig. 21c.

Fig. 22 is a perspective view of a partial modular construction employing the exemplary headers in Figs. 21a, 21b, 21c, and 21d.

Fig. 23 is a perspective view of a modular construction employing the exemplary headers in Figs. 21a, 21b, 21c, and 21d.

Fig. 24a is a perspective view of an exemplary modular construction according to the present invention depicting the use of corner stacks.

Fig. 24b is a detailed view of an exemplary corner closure unit according to the present invention.

Fig. 24c is a detailed view of an alternative exemplary corner closure unit according to the present invention.

Fig. 24d is a top plan view of the modular construction in Fig. 24a and employing the corner closure units in Figs. 24b and 24c.

Fig. 25a is a perspective view of an exemplary modular construction according to the present invention depicting the use of an alternative embodiment of corner stacks.

Fig. 25b is a detailed view of an alternative exemplary corner closure unit according to the present invention.

Fig. 25c is a detailed view of an alternative exemplary corner closure unit according to the present invention.

Fig. 25d is a top plan view of the modular construction in Fig. 25a and employing the corner closure units in Figs. 25b and 25c.

Fig. 26a is a top plan view of an alternative embodiment of a modular construction according to the present invention employing corner stacks.

Fig 26b is a perspective view of the modular construction of Fig. 26a.

Fig. 27a is a top plan view of an exemplary header unit according to the present invention.

Fig. 27b is a perspective view of the header unit of Fig. 27a.

Fig. 27c is a top plan view of an exemplary header unit according to the present invention.

Fig. 27d is a top plan view of an exemplary header unit according to the present invention.

Fig. 27e is a top plan view of an exemplary header unit according to the present invention.

Fig. 27f is a top plan view of an exemplary header unit according to the present invention.

Fig. 27g is a top plan view of an exemplary header unit according to the present invention.

Fig. 27h is a top plan view of an exemplary header unit according to the present invention.

Fig. 27i is a side view of an exemplary embodiment of a header according to the present invention.

Fig. 28 is a perspective partial view of a modular construction according to the present invention and employing the header of Figs. 27a and 27b.

Fig. 29 is a perspective partial view of an alternative embodiment of a modular construction according to the present invention and employing the header of Figs. 27a and 27b and depicting exemplary active reinforcement elements.

Fig. 30 is a perspective partial view of an alternative embodiment of a modular construction according to the present invention and employing the header of Figs. 27a and 27b and depicting exemplary active reinforcement elements.

Fig. 31 is a perspective partial view of an alternative embodiment of a modular construction according to the present invention and employing the header of Figs. 27a and 27b and depicting exemplary active reinforcement elements.

Fig. 32 is a perspective partial view of an alternative embodiment of a modular construction according to the present invention and employing the header of Figs. 27a and 27b and depicting exemplary active reinforcement elements and passive reinforcement elements.

Fig. 33 is a perspective partial view of an alternative embodiment of a modular construction according to the present invention and employing the header of Figs. 27a and 27b.

Fig. 34a is a side elevation of an exemplary application of the system of the present invention.

Fig. 34b is a cross section of an exemplary application of the system of the present invention depicted in Fig. 34f.

Fig. 34c is a side elevation of an exemplary application of the system of the present invention.

Fig. 34d is a side elevation of an exemplary application of the system of the present invention.

Fig. 34e is a side elevation of an exemplary application of the system of the present invention.

Fig. 34f is a perspective view of an exemplary application of the system of the present invention.

Fig. 34g is a perspective view of an exemplary application of the system of the present invention.

Fig. 34h is an enlarged perspective view of a portion of the system of Fig. 34g.

Fig. 34i is a perspective view of an exemplary application of the system of the present invention.

Fig. 34j is a perspective view of an exemplary application of the system of the present invention.

Fig. 34k is a front elevation of an exemplary application of the system of the present invention.

Fig. 34l is a perspective view of the application in Fig. 34k.

Fig. 34m is a perspective view of an exemplary application of the system of the present invention.

Fig. 34n is an enlarged perspective view of a portion of the system of Fig. 34m

Fig. 34o is a front elevation of an exemplary application of the system of the present invention.

Fig. 34p is a cross section of the application of Fig. 34o along the line p-p.

Fig. 34q is a cross section of the application of Fig. 34o along the line q-q.

Fig. 34r is a perspective view of an exemplary application of the system of the present invention.

The illustrations shown herein, of necessity, take presentation liberties. Among these are the sectioning of the retaining wall structures. In order to show close-up detail only small sections of the overall structure are shown. Moreover, only some of the figures indicate the sectioned nature of the components via the use of exposed reinforcing steel. Additionally, for example, the shear reinforcing steel may be omitted, where any rebar is indicated at all. Generally, the soil/rock mass being retained by any given retaining wall is not indicated in these figures.

Detailed Description of the Preferred Embodiments

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. The exemplary embodiments of this invention are shown in some detail, although it will be apparent to those skilled in the relevant art that some features may not be shown for the sake of clarity.

The systems of the present invention possess fundamental characteristics that are common to all of the constituent groups (*i.e.* subsystems). The systems are preferably comprised, at least partially, of pre-cast concrete components, called headers **110** or header units **110**. These components, when stacked one on top of the other, form header stacks **101**. These header stacks **101** are then augmented in a variety of ways. The augmenting members generally form secondary structural members **130**. These components are secondary in the sense that they

are available to resist soil loading, directly transferring these loads to the primary structural members, the header stacks **101**, which transfer the accumulated loads to structural elements which elements mobilize the equilibrating reaction forces which will be explained in detail below. These secondary structural members **130**, or structural members, may be comprised of pre-cast concrete "stretchers", pre-cast concrete panels, cast-in-place (CIP) concrete panels, cast-in-place (CIP) concrete arches, or may be constructed from various configurations of shotcrete.

Another characteristic of the present invention that is consistent throughout these systems, is the manner in which the header stacks **101** are imparted their structural capacity to withstand imposed or applied load. The pre-cast concrete header units **110** that are stacked in a vertical plane, are, at predetermined stages of the construction process, pre-stressed. This pre-stressing is typically imparted to the header stacks **101** via the post-tensioning of tendons **115**, which include, but are not limited to, cables, rods, or threadbars.

Another element of the system is a complementary structural element **1100** (best seen, for example, in Figures 11 and 13), which may be referred to herein as a tieback transfer beam (or TTB). This complementary structural element **1100** may have more than one role. In one principal role, the complementary structural element **1100** will "gather", primarily the lateral components of, the accumulated loads being resisted by the header stacks **101**, and transfer them to the equilibrating reaction forces that are provided by other structural elements, such as tiebacks. The complementary structural element **1100** may also be used to couple a retaining wall horizontally. This would have particular applicability with non-composite systems, that is, systems that do not have transverse reinforcement elements formed in, or passing through, the header unit **110**. For example, the systems employing secondary structural members of arching shotcrete between header stacks **101**, or where the secondary structural members are pre-cast

panels. Further, the complementary structural elements **1100** may be used in other ways. If, for example, there existed a need to apply additional restraint to a limited area of the retaining wall, a complementary structural element **1100** could be included in that area, and so used to provide the necessary reaction(s). Also, these complementary structural elements **1100** may be used together with foundation beams, as continuous elements. This would apply, for example, where the base of the wall was being stepped-up. For example, this would apply where the retaining wall being constructed had a U-shaped frontal elevation. The complementary structural element **1100** may also be used to couple various intersecting retaining wall sections. The complementary structural element **1100** may also be used to support other structural members which members are framing into the wall/support structure and which members are employed to resist non-soil-retention loads (for example, as is illustrated in Figures 34c, 34d, and 34e).

As part of any structure fabricated in accordance with the present invention, header stacks **101** are always present. These header stacks **101** are preferably formed from pre-cast concrete elements, called headers **110**. The headers **110** are preferably vertically stacked, or preferably stacked in a vertical plane. Alternatively, the headers **110** may be rotated such that they are aligned in a horizontal plane. The secondary structural members **130** and the complementary structural elements **1100** may be formed from different materials. Further, the secondary structural members **130** may be positioned either at the front of the structure or at the rear of the structure or at both the front and the rear of the structure. The rear of the structure refers to the face of the wall that contacts the soils **34**(seen in Figs. 34a, 34c, 34d, 34e, 34g, 34p, 34q, and 34r) being retained by it. The front of the structure refers to the face of the wall that does not contact the soil or other retained load. Note also that the secondary structural members **130** and complementary structural elements **1100** that may be chosen for these walls may interact with the

header stacks **101** in various ways. In this respect, there is significant flexibility available to the designer, via the most appropriate selection of a systems group to be installed at a given location.

As used herein, the term "pre-stressing" refers to the process of imparting beneficial stress profiles, to the structure, to the structural member, or structural component, most typically prior to the structure, structural member or component, being subjected to the anticipated, externally applied loads. The process may involve sequenced sets of discrete pre-stressing stages.

As used herein, the term "reinforcement" refers to either "passive reinforcement" or to "active reinforcement". Any particular zone or cross-section within the various structural members that comprise these systems, or any components that comprise such members, may be unreinforced, or possess passive reinforcement, or active reinforcement, or both passive and active reinforcement, depending on the location of the zone or cross-section within the structural system and the structural performance expectations of same.

As used herein, the term "passive reinforcement" refers to reinforcement that is in a neutral state of stress prior to the associated component or member being subjected to applied forces. Where included in reinforced concrete members, a passive reinforcement element is typically referred to as non-pre-stressed reinforcement. The applied forces, that are referred to here, may be induced by body forces, by externally imposed loads acting directly or indirectly on a component or member, or be the result of axial forces that are imposed on a pre-stressed concrete member by pre-stressing forces (typically) prior to the application of external loads. One way to view passive reinforcement is to recognize that it is any reinforcement, included within the member or component, that has not been tensioned specifically to generate a favorable stress regime within the concrete of the structural member or component typically prior to that

member or component being subjected to the body forces and external loads that it is intended to sustain.

As used herein, the term "active reinforcement" refers to reinforcement that has been subjected to positive tensile force(s), thereby inducing therein a state of positive (tensile) stress, typically prior to the associated member or component being subjected to body forces and the anticipated externally applied loads. As used herein, the term "active reinforcement element" refers to any reinforcement element (positioned within the structural component, member, or system and) intended for the structural role of providing and maintaining a pre-stressing force in the structural component or member or in a structural assembly comprised of the same. In accordance with the present invention, this may be done by the jacking of predetermined tensile force(s) into active reinforcement element **115** typically prior to the structural member so stressed being subject to externally applied loads. Active reinforcement element **115** may include, but is not limited to, a wire, a strand, a cable, a rod, or other suitable element specifically designed for the structural role of providing and maintaining a pre-stressing force in the structural component or member or in the assembly composed of same. The active reinforcement element **115** is placed in a state of positive, tensile stress through a process of post-tensioning. Active reinforcement elements may be placed in a state of positive, tensile stress through a process of pre-tensioning. Such pre-tensioned active reinforcement elements may be used in such structural components or members as the stretchers **130**, and the appurtenant structural elements such as element **3450** as shown in Figures 34a, 34b and 34f, for example.

As used herein, the term "pre-tensioning" refers to the process whereby predetermined tension forces are imparted into the pre-stressing active reinforcement element(s), before the concrete of the component or member is placed in the forming molds about the active

reinforcement element(s) and, if included, passive reinforcement elements. After the concrete has gained the necessary strength to withstand the stresses that will be induced at transfer, the pre-stressing forces that were imparted into the active reinforcement elements are released from the pre-tensioning device, and thereby these forces are transferred to, and resisted by, the concrete of the component or member being pre-stressed, and the passive reinforcement elements, if included. The high-strength tendons that may form active reinforcement elements normally take the form of wire, or strand. These tendons possess high performance stress-strain characteristics. In the process of pre-tensioned pre-stressing, where steps are not taken to prevent bond, the active reinforcement elements are typically bonded to the surrounding concrete.

As used herein, "post-tensioning" is the process whereby tension forces are imparted into the active reinforcement elements **115** after the pre-cast concrete components or members have been manufactured and, generally, have been placed in their final position within the structural assembly. The post-tensioning process is also frequently used to pre-stress active reinforcement elements **115** that are used in conjunction with cast-in-place concrete. In either case, where internal pre-stressing tendons are being used, the process requires the provision of suitable ducting to correctly locate the tendons to be stressed. In the case of cast-in-place (CIP) concrete components or members, the internal active reinforcement elements **115** may be placed in the ducts before the concrete is situated or may be fed through the ducts after the concrete has cured sufficiently. In the case where internal active reinforcement elements **115** are being used in conjunction with structural elements or members that are comprised of pre-cast concrete components, for example, pre-cast concrete headers **110**, the "duct" is formed by the successively abutting passthrough ducts **116** that comprise a feature of each header unit **110**. In the case of external pre-stressing tendons the active reinforcement elements **115** generally do not

require such ducting. The exceptions are where such external active reinforcement elements **115** pass through complementary structural elements **1100**, such as tieback transfer beam **1100**, or capping beams, or where these external active reinforcement elements **115** are anchored within a foundation element **1450**, **500** and/or are being locked of at a tieback transfer beam, a capping beam, or other complementary structural element **1100**. In marked contrast to the process of pre-tensioning, and the transfer of pre-stressing force associated with the process of pre-tensioning, the forces that are placed in the active reinforcement elements **115** during the process of post-tensioning are preferably transferred to the structural component, or member, or complementary element, or foundation element, or structural assembly composed of same at reaction and/or lock-off points only. The pre-stressing forces placed in the active reinforcement elements **115** must be sustained by the structural component or member or complementary element, or foundation element, or structural assembly composed of same at two transfer points. The internal active reinforcement elements **115** may be fully bonded to the associated ducts or left unbonded. The bonding of the active reinforcement elements **115** to the ducts, which ducts are already bonded to the surrounding concrete, which was cast in place, where cast-in-place concrete is being used is normally achieved by grouting. Such cast-in-place (CIP) concrete may be found in the foundation elements, the TTBs, and the capping beams. Further, such CIP concrete may also be found in the secondary structural elements that are disposed between the header stacks. Where passthrough ducts **116** are formed in the concrete of the pre-cast components or members, for example, the header units **110**, where abutting features **116** of successive header units **110** form the ducts associated with an active reinforcement element **115**, via grouting of the active reinforcement elements **115** to the ducts so formed, bonding is achieved directly to the concrete of these pre-cast units.

Referring now to Figs. 1 through 5, there is illustrated an exemplary embodiment of the system of the present invention. In the embodiment depicted in Figs. 1-5, system **100** for constructing a pre-stressed modular construction for retaining or supporting an applied load is depicted. It should be understood that the phrase "retaining or supporting an applied load" encompasses one or more of the following: (1) retaining an applied load; (2) supporting an applied load; (3) retaining and supporting the same or different applied load; and (4) retaining or supporting the same or different applied load. The system **100** comprises header stack **101** comprised of a plurality of header units **110**. Header units **110** are preferably formed from pre-cast concrete, but other suitable materials could be used. It should be understood that the present invention is not limited to the use of pre-cast concrete for header units **110**. There is an active reinforcement element **115** configured to cooperate with the header stack **101** so that post-tensioning the active reinforcement element **115** imparts a corresponding pre-stressing force into the header stack **101**. The pre-stressing force applied to the active reinforcement element **115** is transferred to the header stack **101** at predetermined lock-off points **111**. Typically, one end of the active reinforcement element **115** is preferably cast in the foundation **500** (best seen in Figure 5) beneath the header stack **101**. The other end of the active reinforcement element **115**, or at least some point distant from the end cast in the foundation **500**, is stressed to induce the pre-stressing force. The distant end of the active reinforcement element **115**, or at least some point distant from the end cast in the foundation **500**, must be locked off to maintain the transfer of force from the active reinforcement element **115** to the header stack **101**.

A passive reinforcement element, disposed longitudinally through the header stack **101**, may be included within the duct(s) of the header stack **101**, which duct(s) is(are) formed by the passthrough ducts **116** of the header units **110**. Such passive reinforcement element would,

typically, commence within the foundation element **500**, and would be bonded to the header stacks via a process of grouting. Such passive reinforcement element, where included, would work with the active reinforcement element **115** in order to assist the header stack **101** to meet a particular structural performance requirement.

The system may also include passive reinforcement elements **705** (see, for example, Figures 7a and 7b) that extend through passthrough ducts **125** in at least one of the header units **110**. Passive reinforcement elements may either extend vertically or transversely with respect to header unit **110**. The passive reinforcement element **705** may be configured such that it does not carry load distributed in the header stack **101**. However, vertical or longitudinal passive reinforcement elements may be configured to account for additional compressive capacity at the critical sections of the header stack **101** and/or to improve performance of the critical sections under overload conditions.

The passive reinforcement elements **705** may also be useful to provide shear-dowel action between pre-cast components and cast-in-place concrete components, or other secondary structural members, in order to withstand shear-type loads that develop at the interface between such components (*e.g.*, soil loads that would first be resisted by cast-in-place secondary structural members **130c**). The passive reinforcement element **705** preferably extends transversely through a passthrough duct **125** in the header unit.

The passive reinforcement element **705** may also be configured to transfer transverse forces between the header stack **101** and the secondary structural elements adjacent one or both sides of the header stack **101**. In such circumstance, the passive reinforcement element **705** may be bonded and/or mechanically connected to the header unit **110**, with such connection being established over a predetermined portion of the reinforcement element **705**. That is, suitable

bond break is established over sufficient distance of the outer portion or portions of such passive reinforcement element **705** which portion or portions of this element **705** are adjacent the "outer" zones of the header unit **110** so intersected in order to prevent deleterious effects to the concrete of the header unit **110** within these "outer" zones common to both of the intersecting elements **110** and **705**.

The passive reinforcement elements **705** may be placed within pre-cast header unit **110** during casting, as may be the case if the transverse (perpendicular to direction of active reinforcement elements and perpendicular to the front-to-back axis of the header unit) passive reinforcement element was expected to carry compressive forces into and/or through the header unit **110**. Alternatively, the passive reinforcement elements **705** may be fed through the transverse ducts **125** after the associated header unit(s) **110** have been placed in their final positions. The ducts **125** that would be included in the header unit **110** in the latter case allow for several behavioral characteristics. First, from the standpoint of structural performance enhancement of the structural member, or panel,.**130b** (see Fig. 12), between the header stacks **101**, where transverse ducts **125** are located in the header units **110** to align with the rear reinforcement of the panel **130b**, the passive reinforcement elements **705** enable the development of moments at the ends of the panels **130b**. Second, where these passive reinforcement elements **705** are required to sustain tension forces, the presence of the ducts **125** prevents the tensile strains generated within the passive reinforcement elements **705** from attempting to transfer load, via bonding, to the header unit **110** through which it is passing. Third, the structural interdependence, via force continuity through the header stacks **101**, that the presence of the transverse passive reinforcement elements **705** provide, ensures a greater lateral stability of the system.

The concrete components that comprise the header stacks **101** may be either relatively large in size or quite small, and possess relatively high load resistance capacity. The system designer is provided with considerable design flexibility in that header stacks **101** may be chosen from one or more of the range of header units available and which header stacks so formed may be spaced at different spacings to suit different load resisting requirements on the retaining wall via the use of different structural member lengths. Also design flexibility is available via the use of different arrangements of the components within this group. Various arrangements are shown in Figs. 8-10, and will be described in more detail below. Design flexibility is further enhanced via the use of complementary structural elements **1100** such as the tieback transfer beams, as discussed below.

The desired or preferred pre-stressing force magnitude(s), pre-stressing force location(s) and variation(s) associated with each header stack, as required by the designer, may be accommodated by using different types of pre-stressing tendon, different total areas of pre-stressing tendon, as the active reinforcement elements **115**, and by varying the amount of pre-stressing force imparted into these active reinforcement elements **115** together with varying the location(s) of the resultant force(s).

In one embodiment of the invention, the header units **110** that make up the header stack **101** are shaped in a substantially "dog-bone" configuration as shown, for example, in Figs. 3 and 6a-6e. Such header units **110** comprise a center element **118** having a top face **118a**, and a bottom face **118b**; a first end element **112** disposed at one end of the center element **118**; and a second end element **114** disposed at another end of the center element **118**. The first end element **112** and second end element **114** are preferably integrally formed with the center element **118**. The first end element **112** and the second end element **114** each have a top face **112a, 114a** and bottom

face **112b, 114b** respectively that are coplanar with the top face **118a** and bottom face **118b** of the center element **118**. Exemplary embodiments of these headers 110 are best seen in Figures 6a-6e, and 7a-7c, and 21a-21d.

The header units **110** can be either symmetrical or asymmetrical about the center element **118**. In other words, the header units **110** may be symmetrical or asymmetrical about a line perpendicular to an axis of the header unit **110**. Figs. 6a and 6d illustrate two embodiments of a symmetrical header unit **110** that is symmetrical about one dashed line perpendicular to the longitudinal axis of the header units of Figs. 6a-6e. Figs. 6b and 6c show two embodiments of an asymmetrical header unit **110** that are asymmetrical about the dashed line.

It is possible for the header units **100** to be asymmetrical about a plane extending along the length of the header unit **100**. For example, the header unit **100** could have one flat side. Such a header unit **100** could be used at the end of a retaining wall as a "finishing" header unit. Additionally, two such header units could be positioned with their flat sides abutting where a complete break in the wall is desired.

The header units **110** can be further classified as either main header units **110m** or sub-header units **110s**. The main header units **110m** are double-headed (*i.e.*, have both a first end element **112** and a second end element **114**), or single-headed (*i.e.*, have only a first end element **112**). The sub-header units **110s** also are either double-headed or single-headed. In any given header stack **101**, either one of the main header units **110m** or sub-header units **110s** may be symmetrical or asymmetrical. The principal distinction between the main header units **110m** and the sub-header units **110s** is that the main header units **110m** typically extend past the sub-header units **110s** in a header stack **101**. However, it is also possible for the sub-header units **110s** to be identical to the main header units **110m**. For example, Fig. 1 depicts a header stack **101** having

two sections, an upper section **101a** and a lower section **101b**. The upper most sub-header unit **110s** in the lower section **101b** is geometrically identical to the lower most main header unit **110m** in the upper section **101a**. The system **110** can be comprised entirely of main header units **110m** or may be both main header units **110m** and sub-header units **110s**.

It is preferred that the faces of at least one of the first **112** and second **114** end elements have a curved portion **2101**. Such a curvature (best seen in Figs. 21a-23) allows for an optimized bearing line of the structural member **130** onto one of the header units **110**. In that manner, any slight rotational deviation of the header stack **101** about its longitudinal axis, from the most desired position, will not compromise the integrity of the header units **110**. Furthermore, the structural member **130**, or stretcher will not be subjected to loading distributions significantly different from those intended in the design considerations.

In order to maintain an interlocking relationship between the header units **110**, there are shear keys provided on the header units **110**. The shear keys comprise a plurality of indentations **120** on one of the top **118a** and bottom **118b** faces of the center element **118** and a plurality of protrusions **122** on the other of the top **118a** and bottom **118b** faces of the center element **118** corresponding to the plurality of indentations **120**. The protrusions **122** on each sub-header unit **110s** and main header unit **110m** are configured to engage the corresponding indentations **120** in an adjacent header unit **110**. The indentations **120** and protrusions **122** may also be provided on the first end element **112** and/or second end element **114**. The indentations **120** and protrusions **122** may also be provided on part of the first end element **112** and/or part of the second end element **114**. Where such indentations **120** and protrusions **122** are provided on the first end element **112** and/or second end element **114**, or on parts thereof, these indentations **120** and protrusions **122** are preferably continuous and geometrically consistent with such associated

features that are provided on the center element **118**. Preferably, as shown, for example, in Figs. 7a-7c and 21a-21d, the shear keys comprise first corrugations **120a** on one of the top **118a** and bottom **118b** faces of the center element **118**, and second corrugations **122a** on the other of the top **118a** and bottom **118b** faces of the center element **118** corresponding to the first corrugations **120a**. The second corrugations **122a** on each sub-header unit **110s** and main header unit **110m** are configured to nest with the corresponding first corrugations **120a** in an adjacent header unit **110**. The first and second corrugations **120a, 122a** may also be provided on the first end element **112**, or part thereof, and/or second end element **114**, or part thereof. Where such first and second corrugations **120a, 122a** are provided on the first end element **112**, or portion thereof, and/or second end element **114**, or portion thereof, these corrugations **120a, 122a** are preferably continuous and geometrically consistent with such associated features that are provided on the center element **118**.

There are a plurality of passthrough ducts **116** provided in the header units **110** that are configured to receive the active reinforcement elements **115** and/or passive reinforcement elements **115p**, where such passive reinforcement elements **115p** are present in the header stack and have longitudinal orientation with the header stack **101**. The passthrough ducts **116** can be any size or shape, but are preferably cylindrical in configuration, having axes parallel to the longitudinal axis of the header unit **110**. The first end element **112** defines a first passthrough duct **116a** and the second end element **114** defines a second passthrough duct **116b**. The center element **118** may or may not be provided with one or more passthrough ducts **116** to receive active reinforcement elements **115** or passive reinforcement elements **115p**. There are also a plurality of passthrough ducts **125** that extend transversely through the header units **110** to receive passive reinforcement elements **705**. Each of the passthrough ducts **125** are preferably

lined with a conduit that prevents the passive reinforcement element **705** from bonding with each individual header unit **110**, and allows for the ready installation of the element **705** through the header unit **110** after the header unit **110** has been placed into its final position within the header stack **101**. Other structural associations between the transverse passive reinforcement element **705** and the header unit **110** are discussed above.

The header units **110** can be constructed to suit any particular need. They can be designed to accommodate changes in the features such as geometry detail, size, number and location of passthrough ducts **116, 125**; type, size, shape, and location of the shear keys on the top and bottom surfaces; etc.

In one embodiment of the present invention, the active reinforcement elements **115** are internally threaded in the header units **110** through the passthrough ducts **116**. The active reinforcement elements **115** are able to be locked off at lock-off points **111** in lock-off recessions **138** in the header units **110**. Various lock-off elements **140** are provided to secure the active reinforcement element **115** after a pre-stressing force has been applied. The lock-off point is the point at which the post-tensioning force is imparted to the header stack **101**. There are internal lock-off elements **140** to secure the active reinforcement elements **115** within the lock-off recessions. While the lock-off elements **140** are depicted in Figs. 1 and 2 as being planar with the top surface of the header units **110** (*i.e.*, within a lock-off recession **138** in the top surface of the header unit **110**), it would also be possible to provide a lock-off recession in the bottom of the header unit **110** and the lock-off element(s) **140** would then extend into the header unit **110** above. For any lock-off point that is located within the header stack and between such complementary structural elements such as the foundation element, a tieback transfer beam **1100**, or capping beam, there is another geometric arrangement wherein the lock-off recess necessary

for the lock-off point, in order to accommodate lock-off elements **140**, may be accommodated by a lock-off recession in the top surface of the header unit **110** associated with and "below" the lock-off point and a complementary and associated lock-off recession in the bottom surface of the header unit **110** associated with and "above" this same lock-off point.

In an alternative embodiment of the invention, the active reinforcement elements **115** may be disposed external to the header stack **101**. In such a configuration, there are lock-off elements **1610** (best seen in Figs. 16-18) configured to secure the active reinforcement element **115**. As seen in Figs. 19 and 20, the active reinforcement elements **115** may be directed through a harping element **1910** at a harping point **1905**. The harping element **1910** is configured to redirect the active reinforcement element **115** such that the active reinforcement element **115** forms a series of substantially straight segments **1901, 1902, 1903**. The active reinforcement element **115**, when directed through a harping element **1910** is still preferably locked off using a lock-off element **1610** (best seen in Figs. 16 and 17). The active reinforcement element **115**, when directed through a harping element **1910** may additionally and/or alternatively be locked off at such structural elements as a tieback transfer beam **1100**, capping beam, or other complementary structural element. In the configuration depicted in Fig. 19, the lock-off element **1610** would be positioned at a point distant from the harping element located at harping point **1905**, or the active reinforcement element **115** may be locked off at such other structural element as a capping beam or tieback transfer beam element where such are part of the structural configuration. The harping element is preferably not a lock-off element. The harping element **1910** simply serves to redirect the compressive forces induced by active reinforcement element **115** and is not configured as a lock-off point. The harping element **1910** simply redirects the

direction of the force being imparted by the active reinforcement element **115** to the header stack **101**.

The header stacks **101** may include a plurality of active reinforcement elements **115**. The active reinforcement elements **115** may be both internal (*i.e.*, directed through the passthrough ducts **116** in the header units, and, thus, the ducts that are formed via the successive abutting of these passthrough ducts **116** of such header units) and external (*i.e.*, directed through lock-off elements **1610** and harping elements **1910** external to the header stacks **101**). Such external active reinforcement elements **115** may also be situated between the header stacks **101** and configured to cooperate with the header stacks **101** via their interaction with such structural elements as a foundation element, tieback transfer beam, capping beam, or other complementary structural element. Also, in conjunction with such external active reinforcement elements **115** transfer and/or lock-off points may be located on and/or in such complementary structural elements. The header stacks **101** may alternatively have only internal active reinforcement elements **115** or only external active reinforcement elements **115**. Further, these structural systems may, in conjunction with such internal and/or external active reinforcement elements **115**, also include passive reinforcement elements **115p**, which elements **115p** would pass through passthrough ducts **116** and be bonded to the duct formed in the header stack **101**.

Most header stacks **101** possess a plane of symmetry, which is the vertical plane containing the longitudinal axis of the header stack **101**. Where such plane of symmetry of the header stack **101** exists, it is preferable that the pre-stressing tendons such as active reinforcement **115** be placed in a symmetrical fashion about this plane of symmetry and that the active reinforcement elements **115** be stressed such that the resultant force lies essentially within this same plane of symmetry. Such stressing regime is peculiar to each header stack **101**, and

may be the same as, or different from, that stressing regime that is associated with the header stack adjacent.

Coupled between each header stack **101** are structural members **130** that may resist soil loading directly. The loads sustained by such secondary structural members **130** are transferred to the header stacks **101**. The header stacks **101** transfer the accumulated loads to the foundations **500**, and to any other elements that are designed to restrain these header stacks **101** such as complementary structural elements **1100** (explained in more detail below). The structural members **130** may take many forms. The preferred structural member **130** for use with the present embodiment is a stretcher **130a** and is depicted in Figs. 1-5, 8-11, and 22-26b. Stretcher **130a** is preferably made from pre-cast concrete. There is a secondary passthrough duct **136** in the structural member **130** that is configured to receive the active reinforcement element **115**. There may be a plurality of secondary passthrough ducts **136** in the stretchers **130a**, but at least one of the secondary passthrough ducts in the stretcher **130a** must be in registry with at least one of the passthrough ducts **116** in the main header units **110m**. The secondary passthrough duct **136** in the structural member **130** may be configured to receive a passive reinforcement element **115p**.

The structural member **130**, such as a stretcher **130a**, can be coupled between two main header units **110m** such that it abuts the sub-header unit **110s** between the two main header units **110m**. The stretcher **130a** can be positioned between one of the first end element **112** and second end element **114** of the main header units **110m**. Alternatively, stretchers **130a** can be positioned between each of the first end elements **112** and second end elements **114** of the main header units **110m**. In other words, there can be structural members **130**, or stretchers **130a**, on both sides of the header stack **101** or on only one side of the header stack **101**. However, the

stretcher **130a** arrangement need not be identical on both sides of the header stacks **101**. For example, in Fig. 10, there are stretchers **130a** coupled to only a portion of one side **1000** of the header stacks **101** and there are stretchers **130a** coupled to the entire span of the header stacks **101** on the opposite side **1005**. Note that in Fig. 4 the stretchers **130a** in the "rear" of the system (which stretchers have been omitted from the drawing), where the soil mass being retained (not shown) would be positioned with respect to the wall, are not directly contributing to the resistance of the principal loads as are being resisted by the header stack **101**, when those principal loads are applied. In such a configuration, the zone of the stretchers **130a** that intersects with the main header units **110m** may contribute to the resistance of the compression force that is transferred to the header stack **101** by the pre-stressing of the active reinforcement elements **115** where such pre-stressing occurs prior to the application of the principal external loads.

The structural member **130** may also consist of Cast-In-Place (CIP) concrete panels **130c** (see Figs. 12 and 13). The CIP concrete panels **130c** have two distinct roles. The first role remains the direct retention of the soils and the transfer of these soil loads to the header stacks **101**. The second role is to provide additional compression area in the resistance of the primary bending moments that develop over the height of the wall. Alternatively, with different loading and structural configurations, these CIP panels may accommodate active and/or passive reinforcement elements, **115** and/or **115p**, where such elements are configured to work with and to assist the header stacks in resisting the accumulated loads assumed by same.

Note that the effectiveness of this composite action is highly dependent on the position of the CIP concrete panels **130c** relative to the header stack **101** cross-section. Also, the

effectiveness is equally dependent on the nature and location of the equilibrating reaction forces that restrain the wall structure.

The use of cast-in-place concrete panels **130c** for the secondary structural members **130** provides great flexibility for a design engineer. In particular, it is a very simple matter to vary the spacing between header stacks **101**. Moreover, the direction of a retaining wall (described in more detail below with respect to Figs. 8-13) may be changed with ease, and as many times as the site and functional conditions demand. The retaining walls or other type of modular construction constructed from header units **110** coupled with CIP panels **130c** may include plan curvatures, and reverse curvatures. Via the use of Task Specific Construction equipment (TSC equipment), the panels may be constructed using slip-forming techniques. This translates into very rapid construction of high retaining walls.

As with all the other embodiments presented herein, use of CIP panels **130c** allows for the ready inclusion of one or more complementary structural elements **1100**, such as a tieback transfer beam (see, for example, Fig. 11). These complementary structural elements **1100** provide much additional versatility for systems **100**. They may be included at different locations up the height of the wall and, because of the reaction forces that are provided from the ground anchors **1115**, allow for economic retaining wall construction to great height.

The construction of complementary structural elements **1100**, and the seating of the first header unit **110** on top of the complementary structural element **1100**, is facilitated via the use of Task Specific Construction equipment **1480** (TSC equipment), such as that depicted in Figs. 15a and 15b. This will be described in more detail below with respect to a retaining wall fabricated in accordance with the present invention.

Referring to Figs. 11 and 13, a system with a complementary structural element **1100** is shown. Where loading to be resisted by the retaining wall structure is large and where adequate ground anchor **1115** capacity may be developed within legally available ground space or right-of-ways, the use of these complementary structural elements **1100** provides solution opportunities that will tame very demanding retention and/or stabilizing problems. In general, the complementary structural element **1100** reduces the loads that are "seen" by the foundation element(s). As previously described, the load-path that exists in a retaining wall structure is as follows.

The soils being retained exert pressure on the retaining wall's structural members **130**. These elements may be stretchers **130a**, or they may be pre-cast panels **130b**, cast-in-place (CIP) concrete panels **130c**, or some other type of structural component. Such structural members **130** transfer these loads to the header stacks **101**. The header stacks **101** resist the accumulated soil loads, and other loads where such are being resisted by the wall system, and transfer these loads to the structural members that provide the equilibrating reaction forces. Such reaction elements and/or members may be the foundation elements **500**, **1450**, tieback transfer beams **1100**, capping beams, and/or other complementary structural elements, which themselves may be further assisted by other structural elements, such as associated ground anchors **1115**, that collaborate in the development of the required reaction forces. There will be soil pressures exerted directly on the header stacks **101**. However, these pressures depend on the exposed surfaces of the header unit **110** and its geometric characteristics as well as the spacing between the header stacks **101** and the characteristics of the soils being retained.

The foundation **500**, that the header stack **101** is constructed on, and complementary structural elements **1100** if present, provide the necessary reaction forces for and directly to the

header stack **101** of the retaining wall. In certain structural configurations, for example in pure cantilever arrangements, these reaction forces may be provided directly, and wholly, by the foundation beam/footing element itself. Alternatively, in certain configurations of these systems, additional equilibrating reaction forces may be provided via other elements such as ground anchors **1115** and/or piles, for example, to the foundation beam (pile cap, if piles are being used in conjunction with the foundation element **500, 1450**). Other structural elements, such as ground anchors **1115**, may also provide equilibrating reaction forces to complementary structural elements **1100** where present, and to the capping beams where present and where such resisting forces are required at these levels.

As seen in Figs. 11 and 13, the complementary structural element **1100** is a tieback transfer beam preferably disposed between two header units **110** and extending between two or more of the header stacks **101**. A ground anchor **1115** may be coupled to the complementary structural element **1100** to provide additional resistance to an applied load. Other structural element(s) may also, or alternatively, be coupled to the complementary structural element **1100** to provide additional resistance to an applied load. The complementary structural element **1100** can extend across the entire length of a construction or can be located between only some header stacks **101** that comprise the construction. The complementary structural element **1100** is provided with passthrough ducts **1116** that are configured to receive an active reinforcement element **115** or passive reinforcement element **115p**. As with the passthrough ducts **136** in the stretchers **130a**, the passthrough ducts **1116** in the complementary structural element **1100** must be in registry with the passthrough ducts **116** in the header units **110**.

The complementary structural elements **1100** are also provided with a passthrough channel **1130** extending through the complementary structural element **1100**. A ground anchor

1115 is coupled to the complementary structural element **1100** and is configured to extend through the passthrough channel **1130**. Depending upon the direction of force required from the ground anchor **1115**, the passthrough channel **1130** can be provided in a variety of positions. For example, as seen in Fig. 11, there is a raised portion **1120** extending from the complementary structural element **1100** that is in communication with the passthrough channel **1130** for receiving the ground anchor **1115**. Although the figure illustrates the raised portion **1120** on the top of the complementary structural element **1100**, it would be desirable in certain situations to have the raised portion **1120** on the bottom of the complementary structural element **1100**. Further, it would be desirable in certain situations to have a raised portion **1120** on the top of the complementary structural element **1100** as well as have (together with) a raised potion **1120** on the bottom of the complementary structural element **1100** in close vertical proximity with the raised portion **1120** on the top of the complementary structural element **1100**. In Fig. 13, the ground anchor **1115** extends from a front face **1112** of the complementary structural element **1100** through the passthrough channel **1130**.

Referring now to Figs. 27a-33, another embodiment of the components of a system **100** is depicted. The header units **2700** that make up the header stack **2701** in this embodiment comprise a top face **2790** and a bottom face **2780**; a base element **2710** having a first end **2702** and a second end **2704**; a head element **2712** having a first end **2706** and a second end **2708**; and a pair of side elements **2714** extending between the first end **2702** and the second end **2704** of the base element **2710** and the first end **2706** and second end **2708** of the head element **2712**. Either the base element **2710** or head element **2712** preferably extends past the side elements **2714** such that a flange **2705** is formed adjacent one or both side elements. The side elements **2714** may also couple with the base element **2710** such that an indentation **2707** is formed adjacent the base

element **2710** (see Fig. 27a). Alternatively, the side elements **2714** may couple with the head element **2712** to form an indentation **2707** adjacent the head element **2712** (see Fig. 27h). The flange **2705** or indentation **2707** is configured to couple with a structural member **130**. The header units **2700** of this embodiment have an open cell **2709** defined by the base element **2710**, head element **2712** and side elements **2714**. Such a configuration significantly decreases the weight of the header unit **2700** without sacrificing strength and performance of the system. Such configuration significantly allows for the optimization of strength, stiffness, and related properties of the components, and structure constructed with such components, versus the use of materials to obtain such structural performance.

The arrangement depicted in Figs. 27a and 27b is characterized by the convergence of the header webs or side elements **2714** from the back or base element **2710** of each unit **2700** to the front or head element **2712**. The angle of convergence of these units may vary.

A retaining and/or support structure formed with these header units **2700** may employ (1) pre-cast concrete panels **130b**, (2) cast-in-place concrete panels **130c**, (3) a secondary structural element formed from the use of shotcrete **130d** (see, for example, Fig. 28 and Fig. 29), or (4) some other suitable material and/or suitable structural configuration for such secondary structural elements **130**.

The header stacks **2701** formed with these header units **2700** are tied, via the main soil retaining elements (the secondary structural member 130), where desired. The effectiveness of the tie will depend on the particular details of the design. Obviously, the retaining walls and/or support structures so formed are also tied horizontally by the foundation elements **500**, **1450**, the complementary structural elements (where included) **1100**, and the capping beam(s) **3409** (where included).

It is important to note that, while these header units **2700** may be designed and configured to perform their structural roles compositely with, for example, cast-in-place concrete panels **130c**, there are several other ways that these versatile systems may be employed. Consider, for example, the use of reinforced or unreinforced shotcrete arches **130d** between the header stacks **2701** as shown in Figs. 28 and 29. Or, consider the use of pre-cast concrete panels **130b**, which panels may also be pre-stressed by a pre-tensioning procedure, which are connected to the header stacks **2701** via reinforced cast-in-place concrete "welding" or "joining" columns or elements. These connecting columns or elements, with their incorporated continuity reinforcement elements and connections, would cause all the elements brought together in this arrangement to act as an integrated structural system.

The header units **2700** may also have a single set of continuity reinforcing bars **2775** per base element **2710** and/or head element **2712** (see Figs. 27c-27f) located to match the forward rebar of the cast-in-place panels **130c** where such cast-in-place panes are incorporated between or abutting adjacent header stacks **2701**. This "forward" rebar has two roles. One is to provide for positive connection of the header stacks **2701** to the CIP panels **130b** or **130c** between them, abutting them, and on either side of them. This continuity of steel would be provided via mechanical connectors. The second role is to provide a rapid and accurate means by which the forward reinforcing mat of the CIP panel **130c** may be fabricated and/or installed.

As with the header units **110** in the embodiment described previously, the header units **2700** depicted in Figs. 27a and 27b can be produced with a variety of continuity and/or connection rebar configurations. This is, in general, true of all the header units of the present invention that are designed to work integrally with cast-in-place concrete **130c** and/or where positive continuity and/or connection need to be provided for pre-cast panels **130b** placed

between header stacks **2701**. One of the most common reasons for a "second" set of these bars is to provide for the immediate development of negative moment at the ends of these CIP panels **130c**, where they butt the header stacks **2701** (as is indicated in Fig. 32). These continuity rebar sets, which provide for the development of these negative moments at the ends of the panels **130c**, and/or **130b**, may be the only sets provided in a header unit **2700**. These continuity reinforcement elements preferably pass through the header units **2700** within transverse ducts **3210** (see Fig. 32), which transverse ducts are typically included within the header units **2700** during their manufacture.

As with the header units **110** in the embodiment described previously, the passive reinforcement element may also be configured to transfer transverse forces between the header stack **2701** and the secondary structural elements **130c** and/or **130b** abutting or adjacent one or both sides of the header stack **2701**. In such circumstance, the passive reinforcement element **2777** may be bonded and/or mechanically connected to the header unit **2700**, with such connection being established over a predetermined portion of the passive reinforcement element **2777**, only, where such passive reinforcement element **2777** is continuous through the header unit **2700**. As with the header units **110**, where the reinforcement element **2777** is not a continuous element through the header unit **2700**, such element **2777** may terminate within the header unit and protrude out one side of the header unit **2700**. That is, suitable bond break is established over sufficient distance of the outer portion or portions of such passive reinforcement element **2777** which portion or portions of this element **2777** are adjacent the "outer" zones of the header unit **2700** so intersected in order to prevent deleterious effects to the concrete of the header unit **2700** within these "outer" zones common to both of the intersecting elements **2700** and **2777**.

Header units **2700** may be relatively large or small in size and possess high load resistance capacities. Typically, their installation would be found in situations where very large retention capacity is demanded of the retaining structure. This large retaining capacity may be further extended and/or enhanced with the use of complementary structural elements **1100**, which complementary structural elements themselves may, or may not, be augmented with such elements as ground anchors, which tie in, and/or frame in, to the structural system.

As a general note, the degree to which greater efficiencies are derived from the composite systems, where one of the composite systems are used, will depend on several factors. One factor is where the cast-in-place concrete panel **130c** (or pre-cast concrete panels **130b** where such panels are being made to act compositely with the header stacks **2701** associated) frames into the header stack **2701**. This in turn depends on the geometry of the header unit **2700** being used, that is, it depends on the position, on the header unit **2700**, where the CIP panel, or panels, **130c**, or pre-cast panels **130b**, is/are coupled. The header unit **2700** shown in Figs. 27a and 27b places the panel **130c** and/or **130b** at the rear of the header stack **2701** while the header units **2700** shown in Figs. 27g and 27h, for example, place the concrete panel **130c**, or **130b**, near the front of the header stacks **2701** so formed.

A second factor is the presence of complementary structural elements **1100** such as a tieback transfer beam. The presence of one or more of these complementary structural elements **1100**, up the height of a wall, not only reduces the loading on the foundation elements **500**, **1450**, but also directly influences the moment distributions over the height of the wall structure and, in particular, the header stacks **2701** of the wall structure. The moment profile and magnitudes will have a direct influence on the choice of one header type and size over that of another.

The complementary structural elements **1100** acting in conjunction with other elements such as ground anchors **1115**, are not the only way in which lateral restraint may be applied to the retaining wall(s) **3100** at one or more levels up the structure. Where, for example, a "cut-and-cover" is required, and the walls are to be constructed on one or both sides of the cut, beams frequently reach from one side of the "cut" to the other. These spanning beams may then be utilized to act as struts, and thereby provide horizontal restraint to the walls at levels above the foundations.

The header units **2700** depicted in Figs. 27g and 27h are characterized by the divergence of the header webs, or side elements **2714** from the back or base element **2710** of each unit **2700** to their front or head element **2712**. The header stacks **2701** formed with header units **2700** in Figs. 27g and 27h are typically not directly tied together, except at the foundation element(s) **500, 1450**, the capping beam(s), and any complementary structural element or elements **1100**, that may be included. The retaining and/or support structure formed with the header units **2700** in Figs. 27g and 27h may employ (1) pre-cast concrete panels **130b**, (2) cast-in-place concrete panels **130c**, (3) a secondary element formed from the use of shotcrete **130d**, or (4) some other suitable material and/or suitable structural configuration for such secondary structural elements **130**.

The header unit **2700** depicted in Fig. 27g with the single passthrough duct **2716** at the rear of the header unit **2700**, is specifically designed to form header stacks **2701** that only behave as cantilevering structures. That is, they are constructed on the retaining wall's foundation, where all the restraint is provided by the moments and shear forces that develop at the interface between the header stacks and the foundation.

Note, however, where there exists the possibility of reverse moments occurring, as might be the case if the retaining wall and any attached appurtenances were to be subjected to earthquake loading, then a nominal and sufficient capacity to withstand such infrequent events would be required. In such a case, the use of the header unit depicted in Fig. 27h with an additional forward passthrough duct **2716** would be in order. Assuming the wall is a cantilevering structure without assistance from a complementary structural element **1100**, for example, the header unit would be used without necessarily employing active reinforcement elements **115** through the forward duct **2716**. This would be the case because the CIP concrete panels **130c** on either side of the header stacks **2701** would be designed with sufficient vertical reinforcing steel to provide, in composite action with the header stacks **2701**, the necessary reversed moment capacity.

The header units **2700 in 27a, 27b, 27d, 27f,** and **28** through **33** are well suited to resisting very large loads. In particular, where the retaining wall **3100** (see, for example, Fig. 31) is cantilevering from the foundation element(s), because of the large moments that can be resisted with this system, the structure may competently retain very large soil loads. Additionally, the system can readily include structural elements that cantilever out from the face of the wall, or from the top of the wall as shown, for example, in Fig. 34a, 34b and 34f, or may support other structural elements using other supporting mechanisms.

As seen in Figs. 34a, 34b and 34f, the modular construction **800** may be configured to support a cantilever structure **3450** such as a roadway, sidewalk, etc. The modular construction **800** comprises a header stack **2701, 101** comprised of header units **2700, 110**. One or more complementary structural elements **1100** may also be incorporated where desired.

The header units **2700** depicted in Figs. 27e and 27f are characterized by their webs, or side elements **2714**, being parallel. Note that the header units **2700** shown in Fig. 27e do not have a cell **2709**, while the headers in Figs. 27a, 27b, 27c, 27d, 27f, 27g, 27h and 28 do have a cell **2709**. This is because the header unit depicted in Fig. 27e is the smallest in the range of such header units **2700** which header units possess parallel webs or side elements **2714**.

The system having the various types of header units **2700** depicted in Figs. 27a-h may use passive reinforcement elements **2775** and **2777**, or other transverse passive reinforcement elements, that extend through passthrough ducts **3210** (as seen for example, in Fig. 32) in at least one of the header units **2700**. The passive reinforcement element **2775**, **2777** are configured such that it does not carry load distributed in the header stack **2701**. The passive reinforcement elements **2775**, **2777** may also be useful to provide shear-dowel action between pre-cast components and cast-in-place components to withstand loads (*e.g.*, soil loads that would first be resisted by secondary structural members **130**). The passive reinforcement element **2775**, **2777** preferably extends transversely through a passthrough duct **3210** in the header unit **2700**.

Other, longitudinally aligned passive reinforcement elements, which elements are disposed within passthrough ducts **2716**, and which passive reinforcement elements are subsequently bonded to the ducts so formed in the header stacks **2701**, may be configured to account for additional compressive capacity at the critical sections of the header stack **2701** and/or to improve performance of the critical sections under overload conditions.

The passive reinforcement elements **2775**, **2777** may be placed within the header units **2700** depicted in Figs. 27c, 27d, 27e, 27f, and Fig. 32 during casting, as would be the case if the transverse passive reinforcement element, for example element **2775**, was expected to carry compressive forces, or after the header unit **2700** was in place. The ducts **3210** that would be

included in the header unit **2700** in the latter case allow for several behavioral characteristics. First, from the standpoint of structural performance enhancement of the panel **130c** and/or **130b** between and/or abutting the header stacks **2701**, where transverse ducts **3210** are located in the header units **2700** to align with the rear reinforcement of the panel **130c** and/or **130b**, the passive reinforcement elements **2775**, or **2777** enable the development of negative moments at the ends of the panels **130c** and/or **130b**. Second, where these passive reinforcement elements **2775**, **2777** are required to sustain tension forces, the presence of the ducts **3210** prevents the tensile strains generated within the passive reinforcement elements **2775**, **2777** from attempting to transfer load, via bonding, to the header unit **2700** through which it is passing. Third, the structural interdependence, via force continuity through the header stacks **2701** that the presence of the transverse passive reinforcement elements **2775**, **2777** provide ensures a greater lateral stability of the system.

In order to maintain an interlocking relationship between the header units **2700**, shear keys may be provided on the header units depicted in Figs. 27a-27i, and as shown, for example, in Figs. 27-33. The shear keys comprise a plurality of indentations **2120** on one of the top **2790** and bottom **2780** faces of each header unit **2700** and a plurality of protrusions **2122** on the other of the top **2790** and bottom **2780** faces of the header unit **2700** corresponding to the plurality of indentations **2120**. The protrusions **2122** on each header unit **2700** are configured to engage the corresponding indentations **2120** in an adjacent header unit **2700**. The indentations **2120** and protrusions **2122** are preferably provided on the head element **2712**, base element **2710** and side elements **2714**. Preferably, the shear keys comprise first corrugations **2120a** on one of the top **2790** and bottom **2780** faces of the header unit **2700**, and second corrugations **2122a** on the other of the top **2790** and bottom **2780** faces of the header unit **2700** corresponding to the first

corrugations **2120a**. The second corrugations **2122a** on each header unit **2700** are configured to nest with the corresponding first corrugations **2120a** in an adjacent header unit **2700**. The first **2120a** and second **2122a** corrugations are preferably provided on the head element **2712**, base element **2710**, and side elements **2714**. However, it is possible to have corrugations on only one of the elements provided there were corresponding corrugations on the same element of an adjacent header unit **2700**. Where the shear keys, such as corrugations **2120a**, **2122a**, are provided they are preferably continuous and preferably geometrically consistent over those portions of the head element **2712**, base element **2710**, and side elements **2714** where such features are provided.

There may be a plurality of passthrough ducts **2716** provided in the headers **2700** that are configured to receive active reinforcement elements **115** and/or passive reinforcement elements **115p**. The passthrough ducts **2716** can be any size or shape, but are preferably cylindrical in configuration. The head element **2712** and base element **2710** can each define a passthrough duct **2716**. The side elements **2714** may or may not be provided with one or more passthrough ducts **2716** to receive active reinforcement elements **115** and/or passive reinforcement elements **115p**. There are also a plurality of passthrough ducts **3210** that extend transversely through the header units **2700** to receive passive reinforcement elements **2775**, **2777** as mentioned above. Where the transverse reinforcement elements **2775**, **2777** are continuous through the header units **2700** and where such elements **2775**, **2777** are not provided with a capability to transfer transverse forces to the header units **2700**, passthrough ducts **3210** are preferably lined with a conduit that prevents the reinforcement element **2775**, **2777** from bonding with each individual header unit **2700**. As discussed previously, such elements **2775**, **2777** may be connected via bonding and/or mechanical connection to the header units **2700**, but, preferably, this connecting

between these elements **2775**, **2777** and **2700** is over specifically limited lengths of the incorporated passive reinforcement elements, which elements **2775**, **2777** are prevented from bonding over their outer portion or portions of their intersection with the concrete of the header unit **2700**.

The header units **2700** can be constructed to suit any particular need. They can be designed to accommodate changes in the features such as size, number and location of passthrough ducts **2716**, **3210**; size, shape, and location of the shear keys on the top and bottom surfaces, etc.

In one embodiment of the present invention, the active reinforcement elements **115** and/or passive reinforcement elements **115p** are internally threaded in the headers **2700** depicted in Figs. 27a-h through the passthrough ducts **2716**. The active reinforcement elements **115** are able to be locked off at lock-off points **2810** in lock-off recessions **2812** in the header units **2700**, where these lock-off points require such lock-off recessions. There are internal lock-off elements (not shown) to secure the active reinforcement elements **115** within the lock-off recessions **2812**, where these lock-off recessions are/may be required. Such active reinforcement element **115** may also be locked off at, on, or in, such complementary structural elements **1100** as a tieback transfer beam and/or capping beam.

In an alternative embodiment of the invention, the active reinforcement elements **115** may be disposed external to the header unit **2700** either within the cell of, or external to, the header unit **2700**.

The header stacks **2701** may include a plurality of active reinforcement elements **115**. The active reinforcement elements **115** may be both internal (*i.e.*, directed through the passthrough ducts in the header units) and external (*i.e.*, directed through lock-off elements external to the header units). The header stacks **2701** may alternatively have only internal active

reinforcement elements **115** or only external active reinforcement elements **115**. Such external active reinforcement elements **115** may transfer their pre-stressing force or forces to the structural assembly via force transfer points that are included in, on, or at such structural components as foundation elements **500, 1450**, tieback transfer beams **1100**, capping beams, or other complementary structural elements. Also, the internal active reinforcement elements 115 may utilize similar force transfer points, in addition to, or alternatively to, transfer points that are included within the cross-section of the header stack **2701** header units **2700**.

Coupled between each header stack **2701** are structural members **130** that may resist soil loading directly. The soil loads sustained by the secondary structural elements **130** are substantially transferred to the header stacks **2701**. The header stacks **2701** transfer the accumulated loads to the foundations, and to any other elements such as the complementary structural elements **1100**, that are designed to restrain header stacks **2701**. The structural members **130** may take many forms.

The preferred structural member for use with the header units **2700** of the present embodiment is a concrete panel **130b** and/or **130c** disposed between, adjacent, or abutting each header stack **2701**. The structural members **130** are coupled to the header units **2700** at the indentation adjacent the base element **2710** or head element **2712**. There may be passive reinforcement elements **2775, 2777** that are pre-positioned in the indentation **2707** to connect to, and/or maintain the position of, the reinforcement elements of the panels **130b** and/or **130c** associated with the header stack **2701**. The structural element **130** may be a pre-cast concrete panel **130b**, cast-in-place concrete panel **130c**, or may be a shotcrete structural element **130d**. There may also be a bearing strip **3030** (as indicated in Figs. **30** and **31**) or bearing element provided in the indentation **2707**. This bearing element **3030** ensures correct seating of the panel

130b against the header stack **2701** without the development of detrimental stress concentrations in either the panels of header stack **2701**. The bearing strip **3030** is preferably a fully competent and pliable material such as, for example, rubber, polyethylene, neoprene, and butylene, as appropriate to the structural role required of same **3030**. Similarly, Fig. 32 includes a crush strip **3038** which is situated prior to "pouring" the concrete for a cast-in-place concrete panel against header stack **2701**. The crush strip **3038** allows the CIP panel to deform under load without having a detrimental effect on the concrete of the header units **2700**. Moreover, the crush strip **3038** ensures that the load from the panel **130c** is imparted as far into the header stack **2701** as possible (*i.e.* as far from the extreme edges of the header stack as possible).

A complementary structural element **1100**, such as a tieback transfer beam, may be incorporated within a structural system which is comprised partially or largely of header stacks **2701**, wherein such structural element **1100** is preferably disposed between two header units **2700** and extends between two or more of the header stacks **2701**. A ground anchor **1115** may be coupled to the complementary structural element **1100**, or tieback transfer beam, or capping beam, to provide additional resistance to an applied load. The complementary structural element **1100** is provided with passthrough ducts **1116** that are configured to receive an active reinforcement element **115**, or passive reinforcement element **115p**. The passthrough ducts **1116** in the complementary structural element **1100** must be in registry with the passthrough ducts **2716** in the header units **2700** where internal active reinforcement elements **115** and/or passive reinforcement elements **115p** are provided in conjunction with header stacks **2701**. Also, where external active reinforcement elements **115** are provided in conjunction with header stacks **2701** passthrough ducts **1116** in the complementary structural element **1100** must be in registry with such external active reinforcement elements **115**.

The complementary structural elements **1100** are also provided with a passthrough channel **1130** extending through the complementary structural element **1100**. A ground anchor **1115**, or other suitable structural element capable of developing the necessary tension forces required at that location by the particular structural installation, is configured to extend through the passthrough channel **1130**, and is coupled to the complementary structural element **1100**. Depending upon the direction of force required from the ground anchor **1115**, the passthrough channel **1130** can be provided in a variety of positions. There can be a raised portion **1120** extending from the complementary structural element **1100** that is in communication with the passthrough channel **1130** for receiving the ground anchor **1115**. Although it is preferred to have the raised portion **1120** on the top of the complementary structural element **1100**, it would be desirable in certain situations, such as when the ground anchor **1115**, or other suitable structural element capable of developing the necessary tension forces required at that location by the particular structural installation, would need to extend in an upwardly direction, to have the raised portion **1120** on the bottom of the complementary structural element **1100**. Further, it would be desirable in certain situations to have a raised portion **1120** on the top of the complementary structural element **1100** as well as having a raised potion **1120** on the bottom of the complementary structural element **1100** in close vertical proximity with the raised portion **1120** on the top of the complementary structural element **1100**. The ground anchor **1115** can also extend from a front face **1112** of the complementary structural element **1100** through the passthrough channel **1130**.

Referring to Figs. 28-33, various configurations of a modular construction are depicted using header units **2700**. The partial view of a modular construction shown in Figs. 28-29 depicts header units **2700** using active reinforcement elements **115** both internally (*i.e.*, within

the passthrough ducts **2716**) and external to the header unit **2700**. There is a shotcrete panel **130d** disposed between adjacent header stacks **2701**. Figs. 30 and 31, depict the use of pre-cast panels **130b** in between the header stacks **2701** and the use of both internal and external active reinforcement elements **115**. Figs. 32 and 33 depicts the use of CIP panels **130c** between header stacks **2701**.

Referring now to Figs. 24a-26b, the systems in the above embodiments can also be arranged with corner closure stacks **2401** for situations in which the retaining wall **800** must be constructed in other than a straight line. The corner closure stacks **2401** comprise a plurality of corner closure units **2400** and a second active reinforcement element **2115** configured to cooperate with the corner closure stack **2401** so that post-tensioning the second active reinforcement element **2115** imparts a corresponding pre-stressing force into the corner closure stack **2401**. Each corner closure unit **2400** comprises a body element **2412** having a top face **2412a** and a bottom face **2412b** and a junction element **2414** having a top face **2414a** and a bottom face **2414b**. The junction element **2414** is preferably disposed at one end of the body element **2412** and may be integrally formed with the body element **2412**. The body element **2412** is essentially identical for different embodiments of the corner closure units **2400**. The junction element **2414**, however, will vary in configuration depending upon the use of the corner closure stack **2401**. For example, the junction element **2414** can be utilized with either an internal, or included angle **2422** as shown in detail in Figs. 24b and 25b or an external, or excluded angle **2424** as shown in Figs. 24c and 25c. The included angle **2422** and excluded angle **2424** can also be seen in Figs. 24d, 25d, and 26a. The junction element **2414** extends from the body element **2412** in an angular configuration in order for it to receive the secondary structural members **130** from the header stacks **101, 2701** to which it is adjacent or between. The

junction elements **2414** may extend outwardly at any angle, but are preferably configured to form angles of 90 degrees as in Fig. 24b, 270 degrees as in Fig. 24c, 135 degrees as in Fig. 25b, and 225 degrees as in Fig. 25c. The angle that is chosen will be dependent upon numerous design considerations including the spacing between the header stacks **101, 2701** and the corner closure stacks **2401** as well as the dimensions of the header units **110, 2700** and corner closure units **2400**. The corner closure units **2400** are configured similar to the header units **110, 2700** in that they are similarly provided with shear keys (not shown) (*e.g.*, protrusions and indentations or first and second corrugations) and passthrough ducts **2416**. The corner closure stack **2401** may similarly be provided with external harping elements **1910** to receive external active reinforcement elements **115**. Passthrough ducts **2416** may also be configured to receive longitudinal passive reinforcement elements **115p**.

The corner closure stacks **2401** are coupled to the header stacks **101, 2701** by the structural members **130**. Preferably, the structural member **130** is disposed between junction elements **2414** of adjacent corner closure units **2400**. The corner closure units **2400** preferably comprise recessions **2402** in the junction element **2414** that are half the height of a typical stretcher **130a** (see, for example, Figs. 24b, 24c, 25b and 25c). In this regard, the stretcher **130a** is enclosed within the adjacent junction elements **2414**. The recession **2402** in the junction element **2414** could also be equal to the height of the secondary structural elements **130**.

In order to close any large gaps that may result in a construction as a result of using the corner closure stacks **2401**, an augmenting stack **2430** can be provided such as shown in Fig. 24a and Fig. 24d. The augmenting stack **2430** is essentially provided to, as the name suggests, augment the modular construction. The augmenting stack **2430** can be comprised of a scaled

down version of the header units **110** such that it is able to fit within the space constraints created by the corner closure stack **2401** and the adjacent header stack **101**.

Figs. 24a, 25a, and 26b depict the use of the various corner closure stacks **2401** and augmenting stacks **2430**. Each modular construction can make use of a variety of corner closure units **2400**.

Referring now to Figs. 8-10, an exemplary modular construction **800** of the present invention is depicted. The pre-stressed modular construction **800** comprises a plurality of header stacks **101** with a plurality of structural members **130** coupled to at least one of the header stacks **101**. The header stacks **101** are comprised of a plurality of stacked header units **110**. There is also preferably at least one active reinforcement element **115** for each of the header stacks **101** with each active reinforcement element **115** being configured to cooperate with its header stack **101** so that post-tensioning the pre-stressing tendon **115** prior to application of the applied load imparts a corresponding pre-stressing force into its header stack **101** at at least one lock-off point **111**. In a possible alternative embodiment, the active reinforcement elements **115** are not post-tensioned, thereby providing a vertically disposed passive reinforcement element . The modular construction is formed on foundation **500**.

Referring to Fig. 12, an alternative modular construction is shown. The modular construction of Fig. 12 uses cast-in-place concrete panels **130c** between header stacks **101**.

In another aspect of the invention, a pre-stressed modular construction **800** for retaining or supporting an applied load is provided. With reference now to Figs. 22 and 23, the pre-stressed modular construction **800** comprises a plurality of header stacks **101** with a plurality of structural members **130** coupled to at least one of the header stacks **101**. The header stacks **101** of the modular construction **800** are configured as described in the above embodiments. Either

type of header unit **2700, 110** described previously may be utilized to form a modular construction **800** according to the present invention.

The pre-stressed modular construction **800** preferably comprises at least two header stacks **2701, 101**, wherein each of the header stacks **2701, 101** being comprised of a plurality of stacked header units **2700, 110**. There is also preferably at least one active reinforcement element **115** for each of the header stacks **2701, 101**, with each active reinforcement element **115** being configured to cooperate with its header stack **2701, 101** so that post-tensioning the active reinforcement element **115** prior to application of the applied load imparts a corresponding pre-stressing force into its header stack **2701, 101** at at least one lock-off point **111**. As noted above, a preferred active reinforcement element is a pre-stressing tendon such as the tendons shown in, for example, Figs. 1-4, 23, and 28-32. There is also a structural member **130** coupled to the at least two header stacks **2701, 101**. The pre-stressed modular construction **800** further preferably comprises a tieback transfer beam **1100** disposed between two of the header units **2700, 110** and extends between the at least two header stacks **2701, 101**. There is also a ground anchor **1115** coupled to the tieback transfer beam **1100**. The structural member **130** can be a concrete stretcher **130a**, a pre-cast concrete panel **130b**, a cast-in-place concrete panel **130c**, or a shotcrete panel **130d**.

In another aspect of the invention, a method of fabricating a pre-stressed modular construction **800** for retaining or supporting an applied load is provided. A foundation element **1450, 500** is first provided for the construction. On a site-by-site basis, the foundation element **1450, 500** may be augmented by other structural elements, such as ground anchors, piles, or other supporting/restraining elements, that assist the foundation element **1450, 500** in resisting the forces that are transmitted to it by the retaining and support structural system of the present

invention. Referring to Figs. 14a and 14b, one possible manner in which the "first", or "base", header unit (a **header unit 110**, in the case of these illustrative Figures) is provided for, positioned, and connected to the foundation element is shown. Particularly, the foundation element **1450, 500** is cast under and around a suspended header form **1410** which is shaped such that it is compliant with the base header unit **110**, which is the first unit in the assembly of the header stack **101**, but is dimensioned slightly larger, sufficient to facilitate the correct flow and placement of the adhesive/filler grout forming and facilitating the correct connection between header unit **110** and foundation element **1450, 500**. The header forms **1410** are preferably constructed from a high strength material, resilient and abrasion resistant, such as polypropylene, which material may be augmented internally with a strengthening and/or stiffening frame. The header forms **1410** also serve to situate the passthrough tendons, or active reinforcement elements **115** in place for formation of the foundation element **1450, 500**. Where longitudinal passive reinforcement elements **115p** are being installed in conjunction with the header stack **101**, the header forms **1410** also will situate such reinforcement elements **115p**. The foundation element **1450, 500** is cast under and around the forms **1410** and when the foundation element **1450** cures sufficiently, the header forms **1410** are removed, leaving a recess pattern **1420** in which to place/suspend the header units **110**. The header units **110** are placed in the recess pattern **1420**, leaving an annular space **1422** around and beneath the header unit **110**. The annular space is best seen in Fig. 14b. The annular space **1422** is then filled with a grout or epoxy (not shown) which holds the header unit **110** in place, and provides the appropriate connection between the header unit **110** and the foundation element **1450, 500**. The header units **110** must be situated on the foundation element **1450, 500**, such that they are as close to perfectly horizontal as possible as they are the header units on which the header stacks and, hence, the

entire construction **800** is built. In particular, the parallel top and bottom flat surfaces of this "base" header unit **110** must be horizontal as defined by and with respect to the direction which is both perpendicular to the front-to-back axis of the header unit **110** and perpendicular to the longitudinal axis of the header stack being constructed. Alternatively, the normal to the parallel top and bottom flat surfaces of the "base" header unit **110** must be parallel to the axis of the header stack being assembled, whose axis must be in a vertical plane and which vertical plane is perpendicular to the plan curve of construction of the retaining wall, which curve may be a straight line. A very small deviation from this particular requirement would be unacceptable because the deviation would be grossly amplified in a header stack **101** of any significant height. Specifically designed and manufactured construction temporary support equipment **1500** is used to position and then secure the header unit **110** in place while the grout, or other connecting agent, cures. Where header stack construction is being continued on and above a complementary structural element **1100**, an identical or similar procedure may be followed for the preparation for and positioning of the "first" or "base" header unit on and the connection to such complementary element **1100**. Further, such header forms may be used to locate the passthrough ducts that are employed in conjunction with any active reinforcement elements **115** and/or passive reinforcement elements **115p** as are structurally associated with the header stack **101**. This process, specifically employing a header form, which is aimed at the correct and rapid set-up of the first or base header unit on a foundation element **1450, 500**, or complementary structural element **1100**, comprises an essentially identical alternative for each of the various header types **110, 2700** which comprise the collection of header units of the present invention.

The placing of the "first" or "base" header units **110** on the foundation element **1450, 500** may also be accomplished without the header forms **1410**. In such a situation, construction

equipment **1480** (see, for example, Fig. 15a and 15b) would be utilized to hold a header unit **110** in a correct location, possessing correct spatial orientation, suspended above the reinforcement **1458** of the foundation element **1450, 500** and the foundation **1450** concrete would be cast beneath and around it. That is, as determined by the project design, the cast-in-place concrete of the foundation element **1450, 500,** may encroach up the walls of the first, or base, header unit **110** for various job-specific reasons. Again, little tolerance for error is allowed, the header unit **110** must be horizontal. In particular, the parallel top and bottom flat surfaces of this "base" header unit **110** must be horizontal as defined by and with respect to the direction which is both perpendicular to the front-to-back axis of the header unit **110** and perpendicular to the longitudinal axis of the header stack being constructed. Alternatively, the normal to the parallel top and bottom flat surfaces of the "base" header unit **110** must be parallel to the axis of the header stack being assembled, whose axis must be in a vertical plane and which vertical plane is perpendicular to the plan curve of construction of the retaining wall, which curve may be a straight line. Because of these positioning requirements the construction equipment **1480, 1500** is sufficiently robust and both capable of fine adjustment and of maintaining such positional settings during the full process and activities of construction to which such equipment will be subjected. Either method for positioning the first or base header unit **110** on the foundation element **1450, 500** can also be used in positioning the first or base header units **110** on the tieback transfer beams **1100,** or other type of complementary structural element **1100.** This process, specifically suspending a header unit **110,** which is aimed at the correct and rapid set-up of the first or base header unit on a foundation element **1450, 500,** or complementary structural element **1100,** comprises an essentially identical alternative for each of the various header types **110, 2700** which comprise the collection of header units of the present invention. A plurality of

header stacks **101** are constructed on the foundation element **1450, 500** with each header stack **101, 2701** comprising a plurality of header units **110, 2700**. The header units **110, 2700** are those previously described. An active reinforcement element **115** is coupled to each header stack**2701, 101** and is post-tensioned such that it imparts a corresponding pre-stressing force into the header stack **2701, 101**. A passive reinforcement element **115p** may be provided within and through the passthrough ducts of the header units to structurally work in conjunction with the active reinforcement elements **115**, which passive reinforcement elements **115p** augment the structural performance contribution of active reinforcement elements **115**. Such passive reinforcement element **115p**, where included within the header stack construction, is made to work in conjunction with the header stack via bond, which bond is provided via the grouting of the space about the passive reinforcement element **115p** and within the passthrough duct housing such element **115p**.

The construction of the header stacks **2701, 101** comprises stacking a plurality of header units **2700, 110** on the foundation element **1450, 500**. It is desired to pre-position the active reinforcement element **115** in the foundation element **1450, 500**. In such a configuration, the header units **2700, 110** are then fed over the active reinforcement elements **115**, the active reinforcement element **115** passing through a passthrough duct **116, 2716**. The active reinforcement element **115** is then secured to the header stack **2701, 101** as previously described. In an embodiment of the invention, a harping element **1910** is coupled to the header stack at a harping point **1905** such that the active reinforcement element **115** is disposed external to the header stack **101** and is redirected at the harping point **1905** such that the active reinforcement element **115** forms a series of substantially straight segments **1901, 1902, 1903**.

Note that any of the header units **2700**, **110** described above can be utilized with the method of construction of the present invention.

To describe some possible applications and to express the flexibility of the system of the present invention, the following examples are given. It is to be understood that the details in the examples are simplified to describe the primary factors involved in such modular constructions as described. As would be apparent to one of ordinary skill in the art, other factors may affect the design considerations. These examples should not represent any limitation on the present invention. Corresponding reference numerals will be used where appropriate.

Referring to Figs. 34c, 34d, and 34e, the flexibility of the systems of the present invention is depicted. Fig. 34c depicts a structure **3490** being support by a retaining wall **800** which incorporates header stacks **2701**, and a complementary structural element **1100**. The structure **3490** in Fig. 34c is configured to protect the roadway **3500** below from falling debris. There is a shield **3495** which protects the primary shield or structure **3490**. Note that the roadway is supported by a structure such as those described with reference to Fig. 34b. The structure **3490** in Fig. 34e is an elevated roadway that could be constructed in highly congested areas. Element **3495'** in Fig. 34e is a support structure for the elevated roadway **3490**.

The structure **3510** depicted in Fig. 34d is suspended primarily through the use of complementary structural elements **1100**. Such a structure illustrates the vast range of uses of the system of the present invention.

Referring to Figs. 34g and 34h, and Figs. 34m and 34n, another application of the systems of the present invention is shown. The need to simultaneously provide support for the ends of a bridge and to retain the soil mass at those locations is a common problem in highway engineering. The structure that provides for these requirements is commonly known as a bridge

abutment **3401**. Specifically, the abutment **3401** transmits the reactions from the bridge superstructure (*e.g.*, girders) **3402** to the foundation system **3410** and, secondly, retains the soils comprising the earth embankment of the approach roadway.

The different restrictions and requirements that can occur at these abutment locations are numerous. However, the systems of the present invention provide a wide array of options, from which the design engineer may choose, in developing a competent solution meeting the demands of any given bridge site.

The situation that is addressed in Figs. 34g, 34h, 34m and 34n is one where a new freeway system is being pushed through an area that also demands overpass bridges to serve local transportation needs. It has been determined, because of the local peculiarities of the area, that the freeway may be constructed at reduced elevation, with a series of simple overpass bridges. Further, because of restricted right-of-way, the design calls for vertical retaining walls on either side of the freeway. This example demonstrates the use of the embodiment of the header units **110** described above and depicted in Figs. 1-5 and Figs. 22 and 23 in the construction of the necessary retention and support structure.

What is further demonstrated, is the ready inclusion of the overpass bridge abutment. The construction of the bottom slab and the end return walls of the abutment is aided by the use of the same equipment used for the construction of Tieback Transfer Beams (TTBs) and capping beams, which also are used on either side of this abutment.

Fig. 34g shows a general overview of an included abutment **3401**. Figure 34h shows a close-up of the abutment **3401** structure seated on the modular construction of the present invention, with some of the overpass steel-plate girders **3402** being lifted into position. Figures

34m and 34n show a construction similar to that in Figs. 34g and 34h, but include an alternative embodiment of the header stacks of the present invention.

Figure 34a depicts the potential use of the systems of the present invention to support large cantilever structures **3450**. The modular construction **800** is constructed using header units **2700** to form a header stack **2701** to retain a soil load **34**. The system also incorporates a complementary structural element **1100** and a ground anchor **1115** to provide additional capability and stability to the system.

Turning now to Figs. 34b and 34f, the use of the systems to combat cliff erosion is depicted in another application of the system of the present invention. Thousands of communities worldwide, both large and small, are located on a shoreline. Frequently, having been established over long periods, these communities now find themselves being severely encroached upon by the action of the eroding environmental elements.

As is common along part of the California coastline near Santa Cruz, which comprises the general location of the bluff face considered in this example, the base of the cliff is composed of a reasonably competent sedimentary rock. In this location, purisima is the geological name given this sedimentary rock. The soils overlaying the purisima rock, the terrace deposits, are more or less consistent and comprise generally weak, unconsolidated conglomerates. Because of the soil characteristics and the particle grading of these conglomerates, they frequently stand at very steep angles, sometimes forming over-vertical faces. However, these terrace deposits continuously erode, often in a series of non-rotational slip failures, with most erosion activity occurring towards the end of the winter period.

A second and independent form of cliff erosion occurs when failure is induced in the purisima sedimentary rock. This type of failure is caused by the undermining of the relatively

soft rock. The natural attrition of this soft rock at the base is caused principally by the frittering of the purisima, which in turn is caused by the general eroding action of the elements, including wave action. Eventually the undermining progresses to such an extent it causes the sedimentary rock to fall out in slabs and/or blocks, depending on preexisting fracture planes. Ultimately, though sometimes directly, this leaves the conglomerates above unsupported and triggers a consequent failure in the terrace deposits.

In this location, as in many others, there is a public roadway that, when originally constructed, was some distance from the cliff edge. Because of the erosion over the years, the roadway was reduced from two lanes to a single lane. In several places the guard rails were hanging in mid-air. In many other places the roadways are cut completely. It should be noted that the loss of some of the roads and, in many locations, the loss of private property, was caused by earthquake induced rock/soil-mass failures.

There are several ways to combat these types of soil retention and protection problems. The systems of the present invention offer numerous possible solutions.

The design depicted in Fig. 34b addresses several issues. Ultimately, these issues amount to dealing with the time and cost of construction while providing the solution functionality and performance required.

In particular, the solution employs pre-cast cantilever units that these systems naturally incorporate into the structure. The system of the present invention can include large cantilever units (for example, as depicted in Fig. 34a) at very low additional expense (especially when compared to the added functionality acquired), that can regain "property" lost to the effects of erosion. In this situation, this added area can be utilized as vehicular parking, wider pedestrian pathways, bike and roller-blading lanes, and/or lookouts.

What is also significant with the use of cantilever units in general, as attached to the top of the retaining wall, is the freedom of position it affords with regard to the location of the foundation elements. These and other pre-cast concrete elements (as well as structural components made from steel), may be included and/or attached to the retaining wall structure at levels other than the top of the header stacks. In the particular situation depicted in Fig. 34b, the pre-cast concrete cantilever units allow the construction of the foundation element to be located at the interface of the purisima sedimentary rock and the terrace deposits.

Locating the foundation construction at this interface provides several advantages:

- The construction contractor does not need to commence work at the base of the cliff where there is much greater exposure to the whims of the ocean. The typical issue of foundations being inundated with seawater, and the associated problems, are immediately eliminated.
- The depth from the top of finished construction to the foundation beam/pile cap is significantly less than the height of the cliff, and access may be readily established from the roadway above.
- Because of the competency of the sedimentary rock, the piles may be installed most rapidly, typically not requiring any shoring, and thus allowing for the optimized use of the drilling rigs. In the few locations where the rock cover is insufficient to contain the bursting pressures generated by the compaction of the wet concrete, the upper few feet of the pile may be sleeved.
- Ground anchors are installed under optimum conditions.
- The foundation beam/pile cap is then readily placed to the accuracy required by the system for the first layer of header units, and the placing of remaining pre-cast modules may proceed with rapidity.
- The pre-cast cantilever units are installed and, having already developed ample strength, may immediately carry the loads of the forms, rebar and concrete necessary to complete the structure.

One of the most significant savings established by the approach that can be taken with these systems is the elimination of wall construction over the height of the exposed purisima sedimentary rock.

Figs. 34i and 34j illustrate the use of headers **2700** in conjunction with cast-in-place (CIP) concrete panels **130c**. The CIP panels **130c** in the illustration are formed with simple patterned front faces. The faces of the panels **130c** can be patterned in various ways to meet the requirements of the owner. The use of complementary structural element **1100** along with the restraining ground anchor **1115** forces which apply at the complementary structural elements **1100**, provide for efficient use of the header stacks **2701** in conjunction with the CIP panels **130c** because of the composite action which may develop between these components. Fig. 34j depicts the rear face of the wall shown in Fig. 34i.

Figs. 34k and 34l further illustrate the flexibility of the systems of the present invention. In a situation where a sloped construction is required, the header stacks **101** are stepped and the capping beam **3409** is formed to abut the adjacent header unit **110**. The cast-in-place concrete panels **130c** are formed to substantially fill the area between the header stacks **101**. The complementary structural element **1100** depicted in the figure is physically close to the capping beam **3409** due to the steep slope of the capping beam **3409**. Note that the complementary structural elements **1100** for any construction may step at various intervals without having to be continuous across the entire length of the wall **800**.

Figures 34o, 34p, 34q illustrate a situation where there is significant rock formation obstructing the path of where a construction is desired. The rock formation may be too costly to remove or may need to be left in place for various other reasons. In such a situation, the modular constructions of the present invention may be configured to provide a superior solution, readily

overcoming such obstacles. Note that the element that serves as a complementary structural element **1100** at the section of the wall depicted in Fig. 34q serves as the foundation element **500** for the section of the wall depicted in Fig. 34p. Together with complementary structural elements **1100**, the appropriate location, spacing, capacity, and declination of ground anchors **1115** provides a great scope of application and flexibility of the systems of the present invention.

The potential use of ground anchors **1115** is further illustrated in Fig. 34r. In this example an elevated railroad line built on a level crossing is depicted. The system incorporates cantilever units at the top of opposing retaining walls. Very large lateral forces may develop during and after construction, which forces will act on the retaining wall structure **800**. A system from the present invention maybe chosen with the capacity to withstand these lateral forces (and the resultant moments and shears, etc.) in a strictly cantilever action. Another option that significantly reduces, or may eliminate, the moments and the shear forces "seen" by the foundation element **500** at the base of such wall construction, is afforded via the use of incorporated complementary structural elements **1100**, which elements **1100** may then be "tied together" via horizontal ground anchors **1115**, or similar ties **1115**. Note that such ties **1115** are also employed as shown between the foundation elements **500** themselves.

Conclusion

While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.